ARMY RESEARCH LABORATORY

Natural Aerosol Extinction Module XSCALE 92 User's Guide

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ARL-TR-273

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13. ABSTRACT *(Maximum 200 words)*

XSCALE* is an empirical and semi-empirical model based on measurements and theoretical calculations of extinction due to naturally occurring aerosols. This model can be used to calculate transmission along horizontal and slant paths near the surface of the earth. This description of XSCALE is an enhancement of descriptions previously released.

* XSCALE applies to the wavelength range 0.2-12.5 µm.

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1. Introduction

XSCALE calculates the transmittance through naturally occurring aerosols of haze, fog, rain, snow, and ice fog. Slant path transmittance for wavelengths of 0.2 – 12.5 μm are calculated through haze, fog, cloud, and blowing snow; these transmittances are calculated either at a single wavelength or as a band average. The module XSCALE is very similar to XSCALE 87 and the interim XSCALE 89. A few enhancements have been added and, in some cases, the execution time has been reduced. The algorithms are empirical and semi-empirical models of theoretical calculations and measurements. The physical models and algorithms will be discussed in chapter 2.

1.1 Names of Things

EOSAEL standard typefaces will be used for descriptions:

1. Names of modules will be in new helvetica narrow style.
2. Variable and subroutine names will be in courier style.
3. Sample input and sample output will be in typewriter style but monospaced to allow column alignment.

1.2 Availability

EOSAEL 92 is available at no cost to U.S. Government agencies, specified Allied organizations, and their authorized contractors. U.S. Government agencies needing EOSAEL 92 should send a letter of request, signed by a branch chief or division director, to U.S. Army Research Laboratory (ARL). Contractors should have their Government contract monitor send the letter of request. Allied organizations must request EOSAEL 92 through their national representative. The EOSAEL 92 point of contract at ARL is Dr. Alan Wetmore.

Intended uses should be included with requests. Requests should also include the type of nine-track tape necessary for computer execution. Tape formats are as follows: ASCII, UNIX "tar" format in either 1600 or

6250 bpi, or SUN cartridge. EOSAEL 92 cannot be supplied on any other media. Documentation for modules are included.

1.2.1 *Mailing Address*

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2. Background

Weather has a profound effect on the performance of all electro-optical (EO) devices that depend on the propagation of electromagnetic energy through the atmosphere. XSCALE models the wavelength dependence of transmittance on natural aerosols (i.e., haze, fog, low clouds, snow, rain, and ice fog) for line-of-sight (LOS) paths within 2 km of the Earth's surface. The aerosols are assumed to be horizontally homogeneous. Beer's law is used to calculate horizontal transmittance:

$$T\lambda(R) = \exp(-K\lambda R) \tag{1}$$

where

$T\lambda(R)$ = the transmittance at range R and wavelength λ
$K\lambda$ = the extinction coefficient at λ.

The wavelength range modeled by XSCALE is: $0.2 < \lambda < 12.5$ µm. The model has been under development since 1980 at ARL's Battlefield Environment Directorate (BED), formerly the U.S. Army Atmospheric Sciences Laboratory (ASL). Aerosols will be individually discussed in this chapter. Horizontal LOS paths with be considered first, then slant LOS paths.

2.1 Attenuation Along Horizontal Lines of Sight

2.1.1 Hazes

An air mass containing particles from the Earth's surface is referred to as haze. The particles become part of the air mass either by the action of surface winds in rural or maritime settings or by human activities in urban settings. The three different air masses available in XSCALE are mathematically distinguished by representative particle size distributions.

The rural aerosol is a continental-type air mass composed of 70 percent water soluble substances and 30 percent dust-like particles. The urban aerosol is the rural aerosol with the addition of soot and combustion products. The urban particle size distribution is a combination of the rural distribution plus carbonaceous particles in a ratio of 4 to 1. The maritime aerosol is the rural distribution without large particles and with 1 percent

given over to a sea-salt distribution. While the sea-salt fraction depends on location and weather, the 1 percent value was chosen as an average.

A theoretical aerosol model of the lower atmosphere is used to calculate extinction and absorption coefficients for the rural, urban, and maritime hazes. [1] This model assumes a bimodal, log normal particle size distribution of the following form:

$$\frac{dn(r)}{dr} = \sum_{i=1}^{2} \frac{N_i}{\ln 10 \sqrt{2\pi}\; r\; \sigma_i} \exp - \left[\frac{(\log r - \log r_i)^2}{2\sigma_i^2} \right], \quad (2)$$

where

r_i = the mode radius of mode i
N_i = the density associated with r_i
σ_i = the standard deviation for mode i.

Table 1 contains the values of r_i and σ_i. [1] This equation is equivalent to that used in the Mie calculation module AGAUS except that the denominator of the exponential in AGAUS is 2 $(\ln(\sigma_i))^2$ and the numerator in AGAUS uses the natural rather than the common logarithm. Consequently, the standard deviation used in AGAUS is 10 raised to the Shettle-Fenn standard deviation:

$$\sigma_A = 10^{\sigma SF}. \quad (3)$$

Table 1. Mode radii and standard deviations of the XSCALE aerosols. The standard deviation values are appropriate for the Shettle-Fenn particle size distribution of equation (2)

	Maritime		Rural		Urban	
Relative Humidity	N_1 = 0.99, σ_1 = 0.35	N_2 = 0.01, σ_2 = 0.4	N_1 = 0.999875, σ_1 = 0.35	N_2 = 0.000125, σ_2 = 0.4	N_1 = 0.999875, σ_1 = 0.35	N_2 = 0.000125, σ_2 = 0.4
	r_1	r_2	r_1	r_2	r_1	r_2
0%	0.02700	0.1600	0.02700	0.4300	0.02500	0.4000
50%	0.02748	0.1711	0.02748	0.4377	0.02563	0.4113
70%	0.02846	0.2041	0.02846	0.4571	0.02911	0.4777
80%	0.03274	0.3180	0.03274	0.5477	0.03514	0.5805
90%	0.03884	0.3803	0.03884	0.6462	0.04187	0.7061
95%	0.04238	0.4606	0.04238	0.7078	0.04909	0.8634
98%	0.04751	0.6024	0.04751	0.9728	0.05996	1.1691
99%	0.05215	0.7505	0.05215	1.1755	0.06847	1.4858

The particle size distribution is a function of the locale where the air mass was formed and the relative humidity. Particles grow with increasing humidity. [2] Based on the dn/dr of equation (2) and the refractive indices of the constituents, the standard Mie theory is used to calculate the extinction and absorption coefficients. [1] The resulting coefficients have been tabulated for each haze at 8 relative humidities (0, 50, 70, 80, 90, 95, 98, and 99 percent) and at 31 wavelengths (in the range of 0.2 – 12.5 μm) for each humidity. [1] These results are normalized at each humidity to the 0.55 μm extinction and included as a table in XSCALE.

XSCALE uses the empirical Koschmieder relation:

$$K_{0.55} = \frac{3.912}{V} \tag{4}$$

to determine $K_{0.55}$ from V, where V is the meteorological range, or visibility, and 3.912 corresponds to a 2 percent contrast threshold. XSCALE uses input values for relative humidity, visibility, and wavelength to scale the visible extinction to the infrared (IR) extinction. This is achieved by linear interpolation between the tabulated extinctions for wavelengths and logarithmic interpolation for the humidity. The subroutines `TRPCTL` and `INTERP` handle these interpolations.

Since 1980, BED, formerly ASL, has conducted field tests to measure particle size distributions under low visibility conditions. [3,4,5] Data from the Project Meppen 80 test, conducted during the winter in western Germany, and the Cardington test, conducted during the winter of 1983 in England, were used for comparison with theoretical air mass particle size distributions. Figures 1 and 2 show the particle size distributions from the Cardington test for rural and maritime air masses compared to the theoretical rural and maritime aerosols with 90 percent relative humidity. Figure 3 shows a similar comparison between a rural air mass measured during the Meppen test and a theoretical rural aerosol at 70 percent relative humidity. Figure 4 compares a maritime air mass measured at Meppen to a theoretical maritime aerosol at 70 percent relative humidity.

In figures 1 through 4, the particle size distributions measured during several balloon flights have been normalized to the particle surface area. The vertical bars through the data points represent ±1 standard deviation. The small standard deviations in figure 1 are due to the small data set available for that air mass type. The noticeable bump in the data in the 0.7 – 1.0 μm range possibly is due to the local addition of pollutants. The overall agreement justifies the use of the model to predict extinction and absorption coefficients of the atmosphere. There is no comparison of measured extinction coefficients to model predictions for these tests, although the Mie theory is very accurate for these particles.

This model does not predict extinction and absorption coefficients that vary with humidity and wavelength. Graphs of the extinction coefficients for maritime, rural, and urban aerosols are shown in figures 5 through 7. These figures show the wavelength variation of the extinction coefficient at 8 humidity levels. The plots represent an aerosol with a constant number density; at any wavelength, the extinction increases with humidity. These figures are identical to the corresponding figures in the Shettle-Fenn report. [1] The extinction coefficient is the sum of the scattering and absorption coefficients.

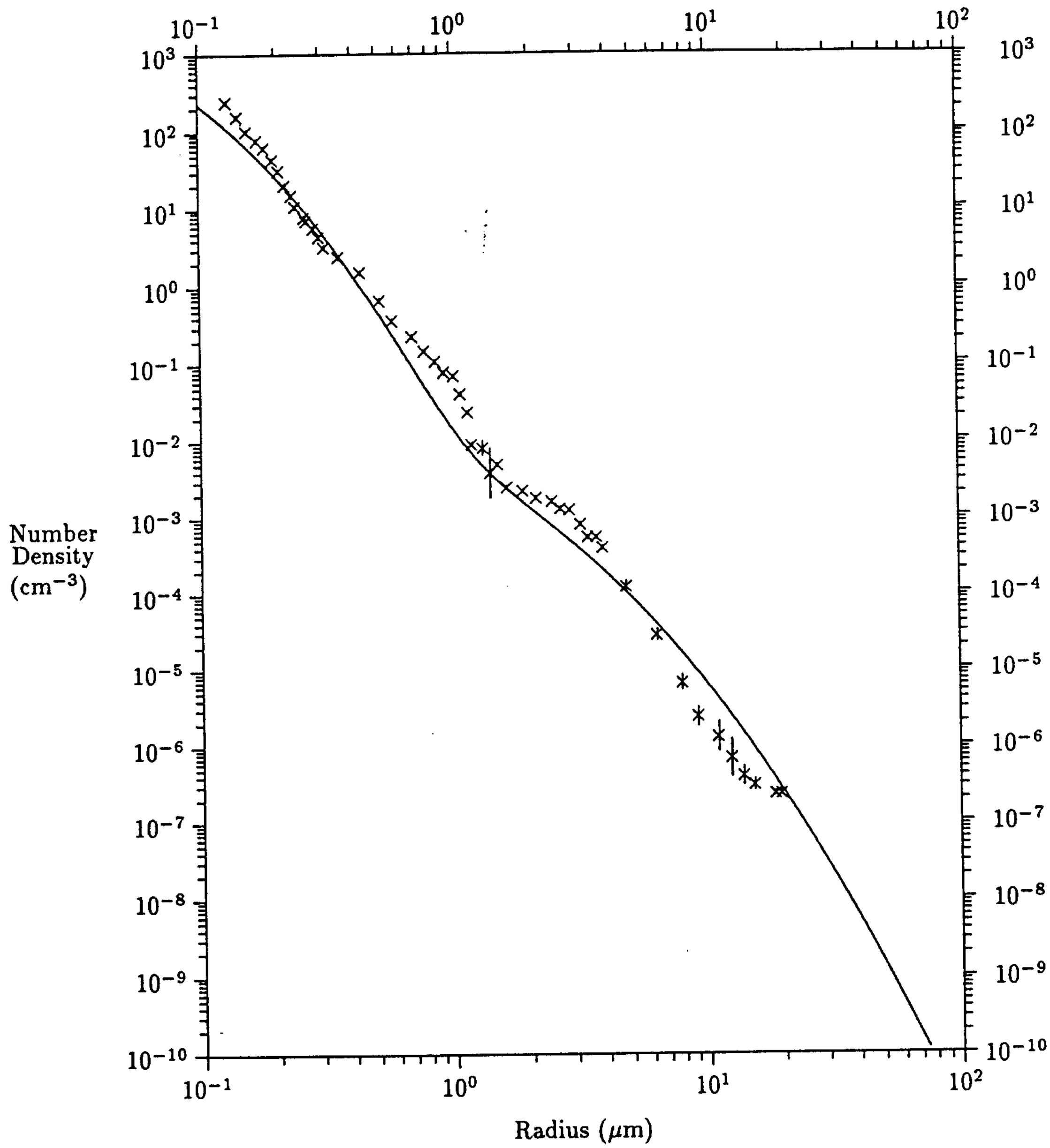

Figure 1. Rural aerosol, 90 percent relative humidity. Measured and modeled particle size distribution for a rural aerosol from the Cardington test. The solid line represents the theoretical size distribution that has been normalized to the particle surface area. The vertical bars represent ±1 standard deviation about the data points.

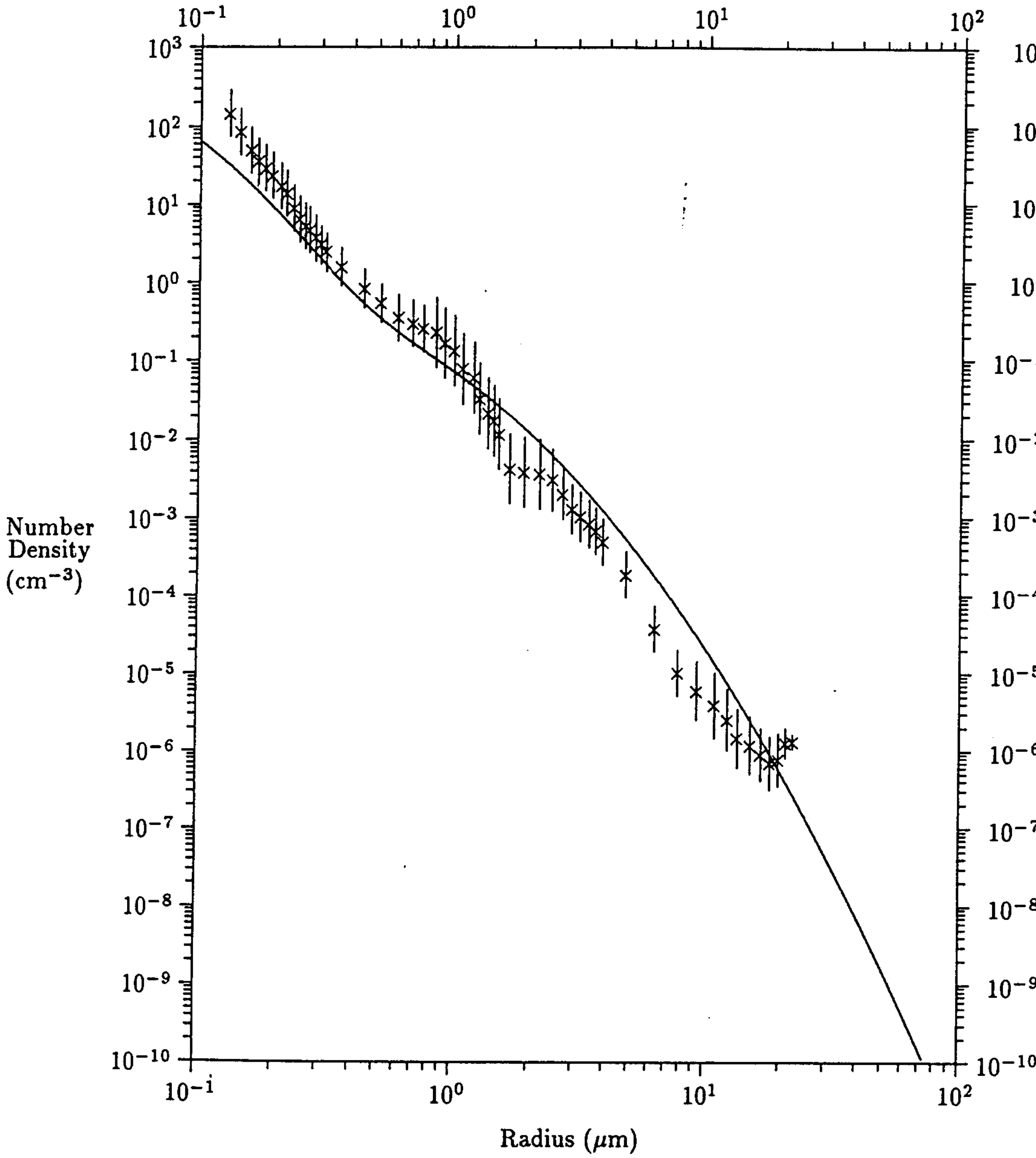

Figure 2. Maritime aerosol, 90 percent relative humidity. Measured and modeled particle size distribution for a maritime aerosol from the Cardington test. The solid line represents the theoretical size distribution that has been normalized to the particle surface area. The vertical bars represent ±1 standard deviation about the data points.

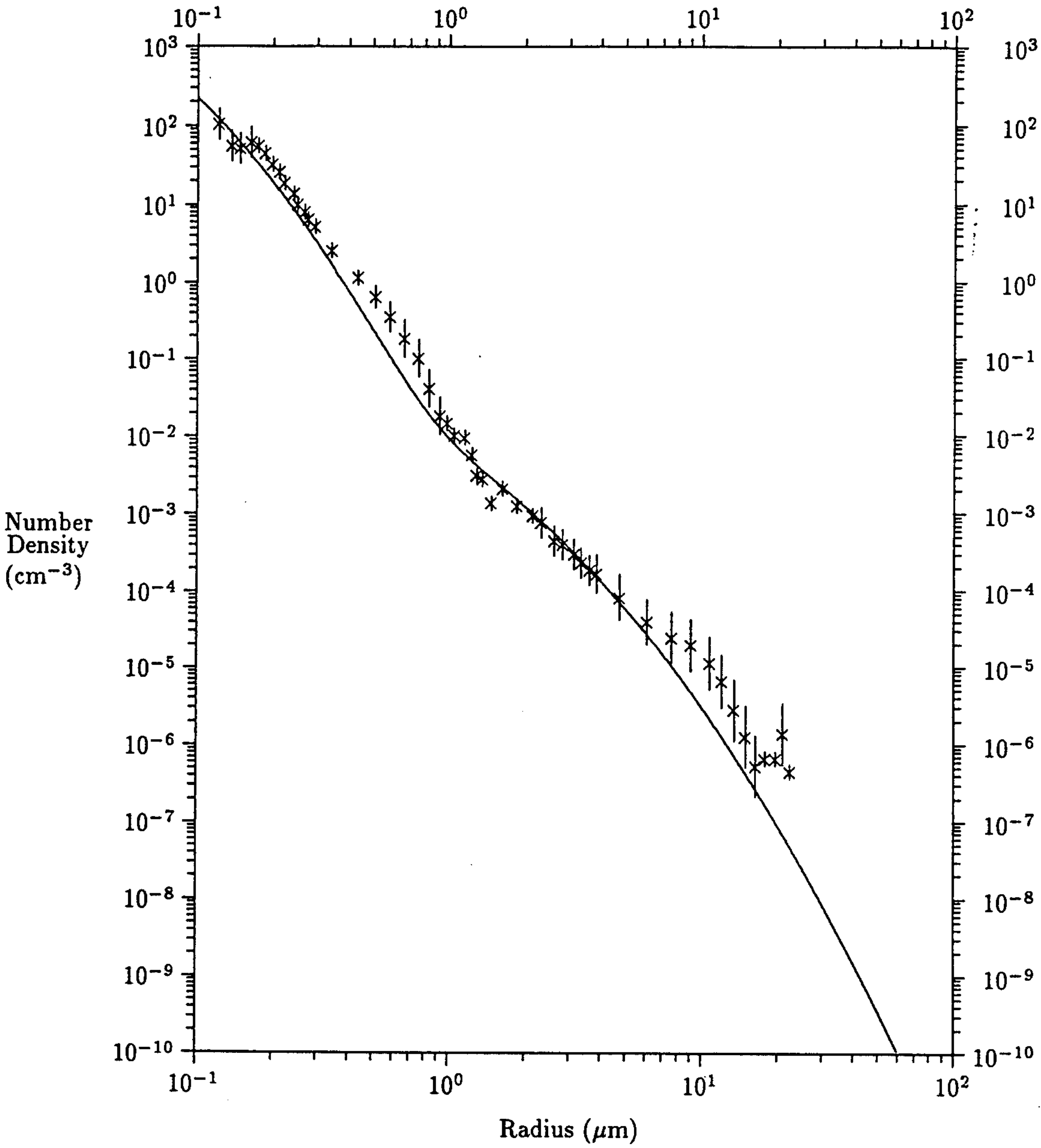

Figure 3. Rural aerosol, 70 percent relative humidity. Measured and modeled particle size distribution for a rural aerosol from the Meppen 80 test. The solid line represents the theoretical size distribution that has been normalized to the particle surface area. The vertical bars represent ±1 standard deviation about the data points.

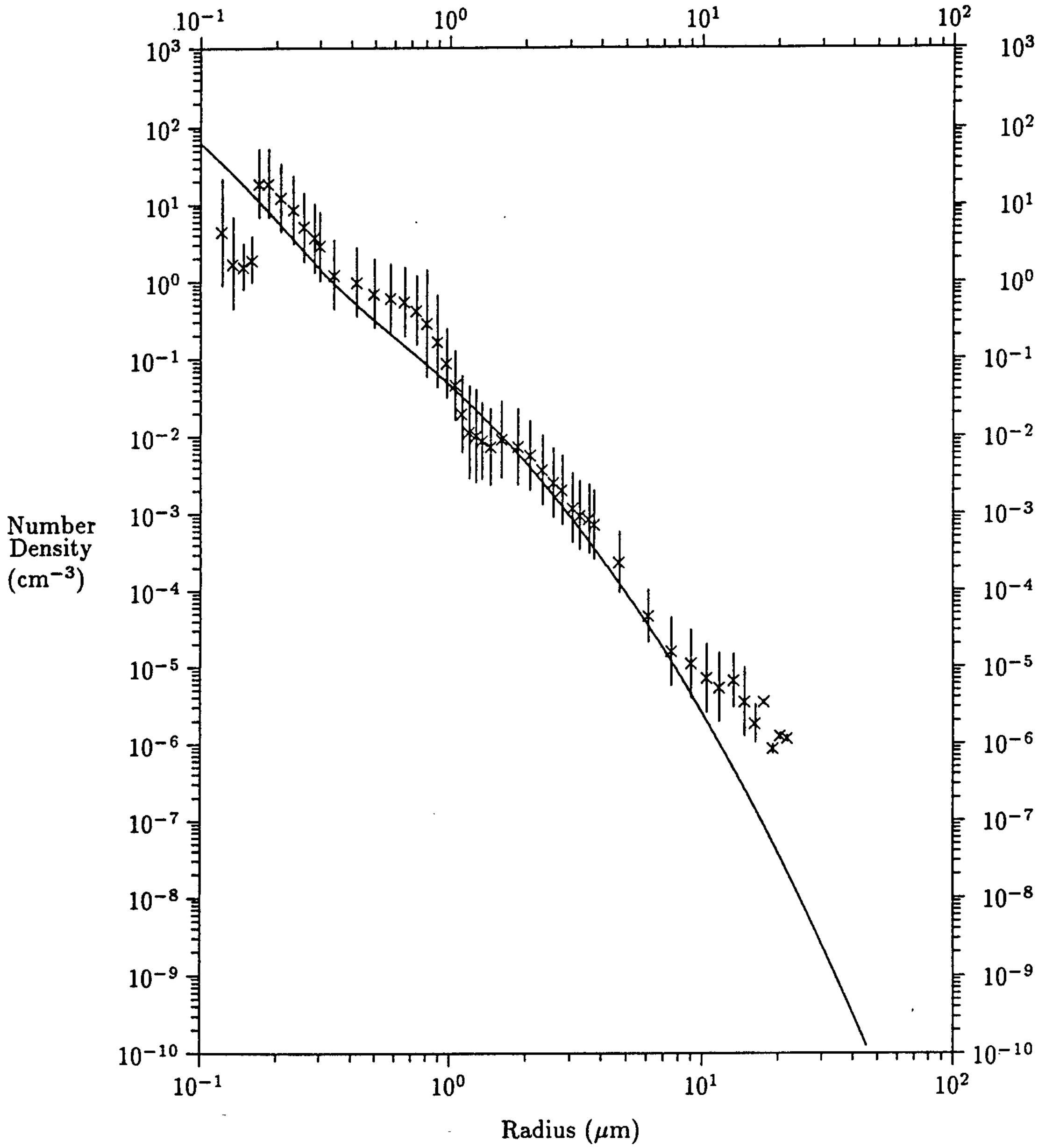

Figure 4. Maritime aerosol, 70 percent relative humidity. Measured and modeled particle size distribution for a maritime aerosol from the Meppen 80 test. The solid line represents the theoretical size distribution that has been normalized to the particle surface area. The vertical bars represent ±1 standard deviation about the data points.

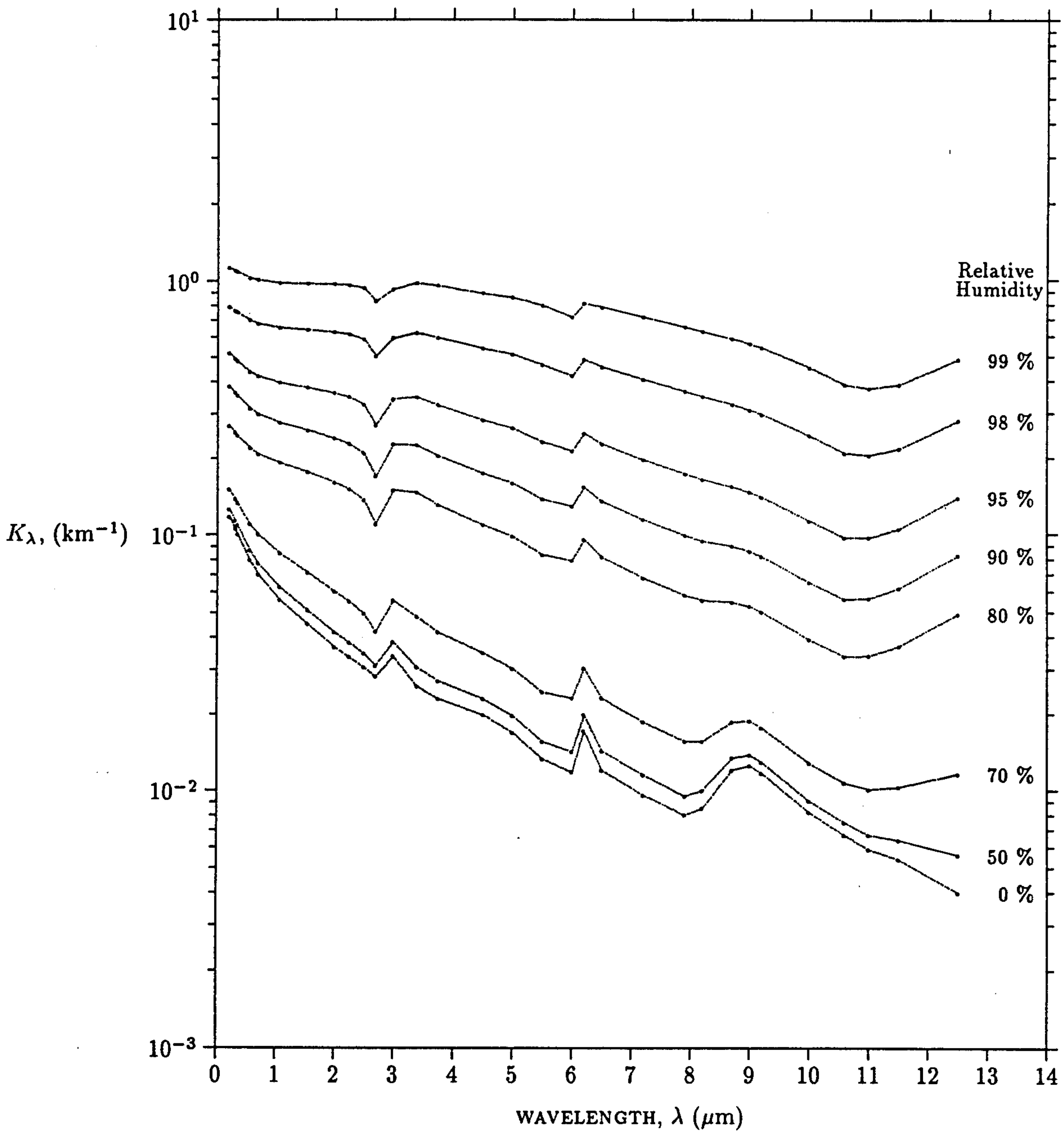

Figure 5. Maritime extinction as a function of wavelength and relative humidity for a constant density of 4,000 particles/cm^3. Semilog scale used.

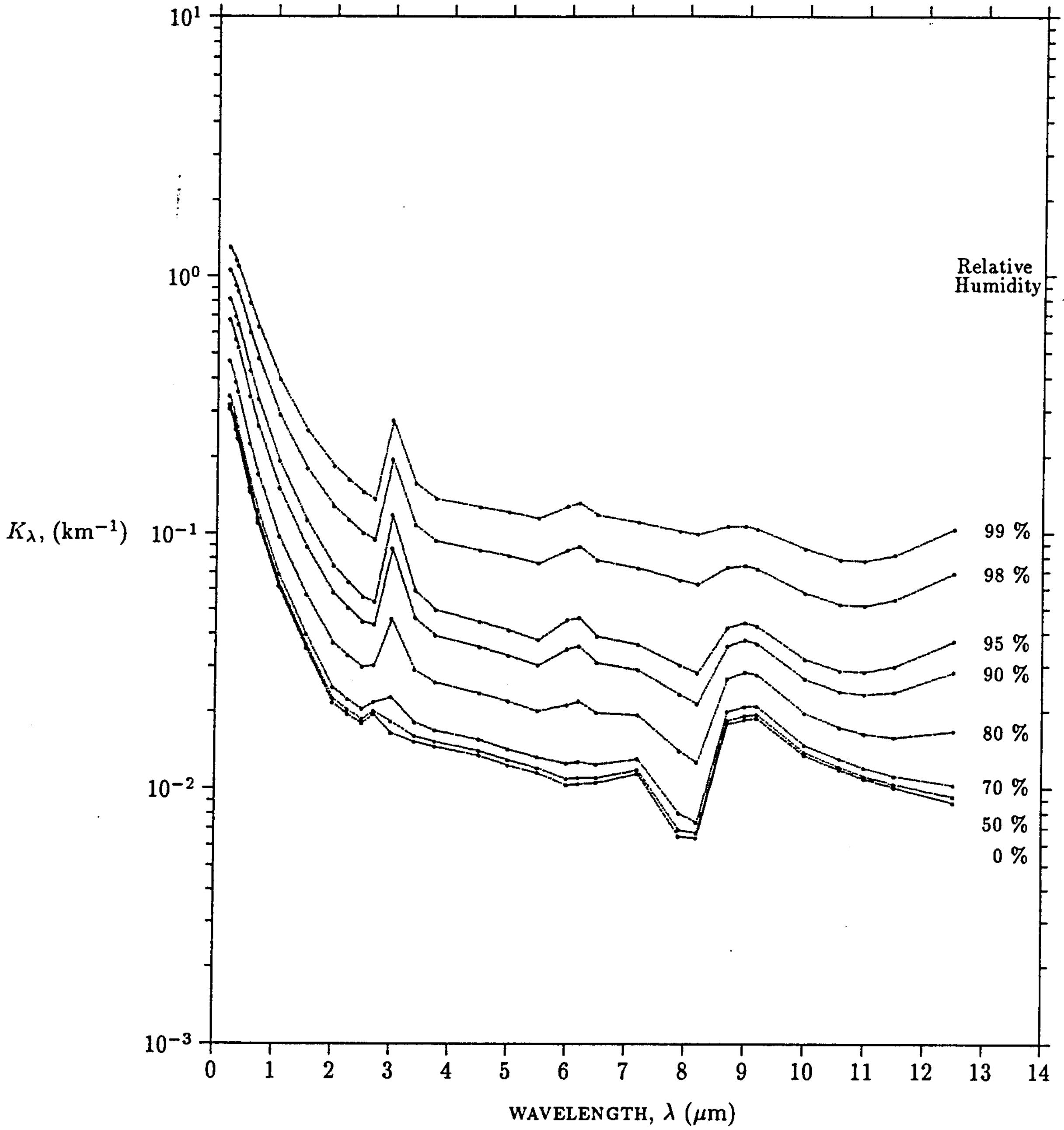

Figure 6. Rural extinction as a function of wavelength and relative humidity for a constant density of 15,000 particles/cm³. Semilog scale used.

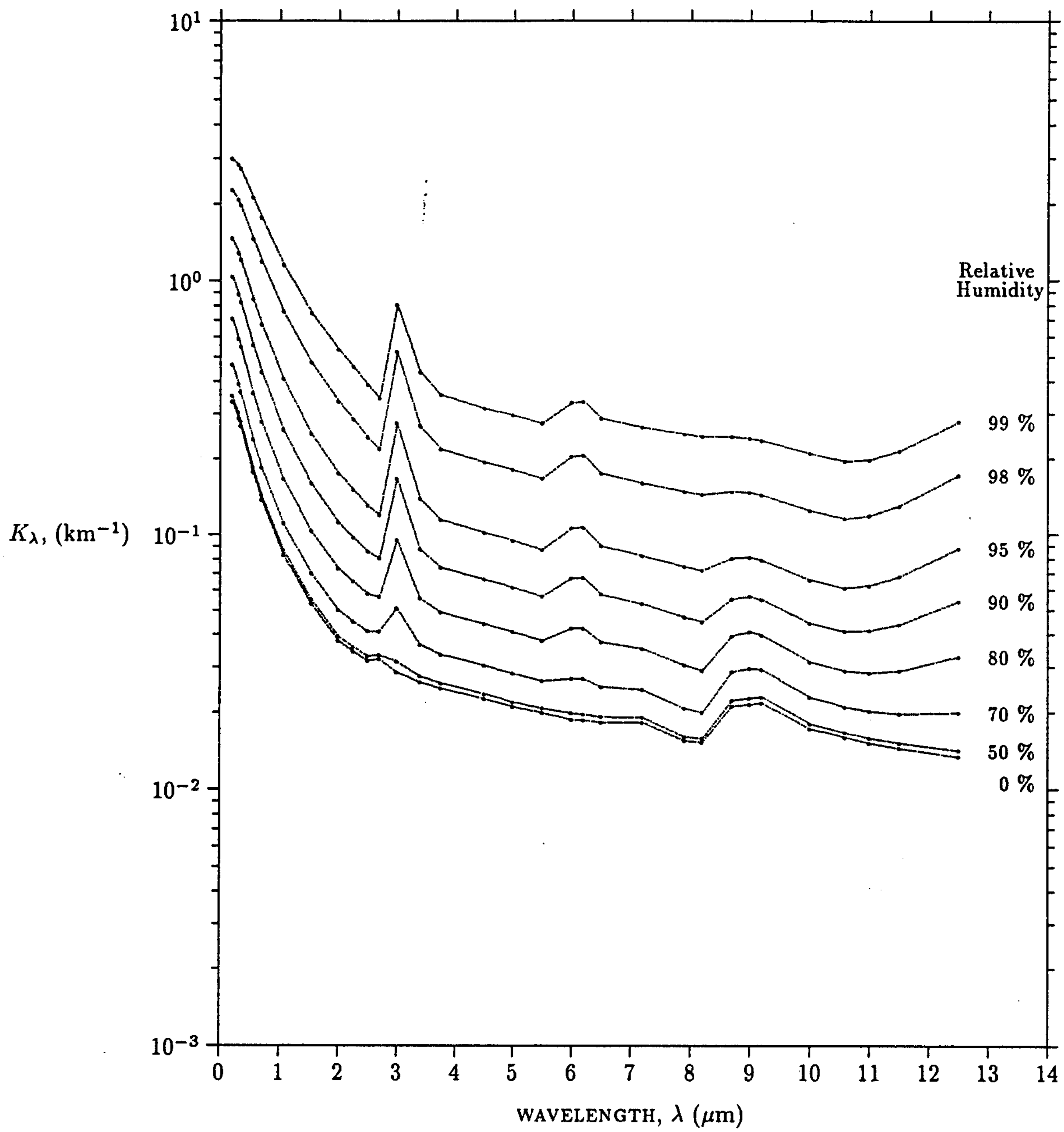

Figure 7. Urban extinction as a function of wavelength and relative humidity for a constant density of 20,000 particles/cm³. Semilog scale used.

2.1.2 *Fogs*

Two models represent the range of natural fog types. The models are Mie calculations based on a particle size distribution. Mie theory calculates the scattering and absorption of an incident plane electromagnetic wave by a single spherical particle. To determine the attenuation of a collection of particles, Mie calculations are performed for each type and size particle, then summed over the particle distribution. [6]

The two models used for fog types are the same ones used in LOWTRAN 7; [7] a complete description can be found in LOWTRAN 6. [8] The two models represent typical advection and radiation fogs. [9] Fog particle size distributions are characteristic of more situations than their labels imply. Consequently, the labels will be dropped, and the particle size distributions will be identified as fog-one and fog-two. These fogs have size distributions represented by Deirmendjian's modified gamma distribution: [10]

$$\frac{dn}{dr} = Ar^{\alpha} \exp(-br). \tag{5}$$

For fog-one, this equation becomes:

$$\frac{dn}{dr} = 0.06592r^{3} \exp(-0.3r). \tag{6}$$

For fog-two, this equation becomes:

$$\frac{dn}{dr} = 607.5r^{6} \exp(-3r). \tag{7}$$

The fog models are implemented in the same manner as the haze models. The extinction and absorption coefficients have been computed, normalized to the extinction at 0.55 μm, and tabulated for the 31 wavelengths (only 100 percent humidity is considered). XSCALE then interpolates between the extinction values at the requested wavelength. Figure 8 shows the wavelength dependence of the two fog models. Fog-two should be used for visibilities above 200 m, and fog-one should be used for visibilities below 200 m.

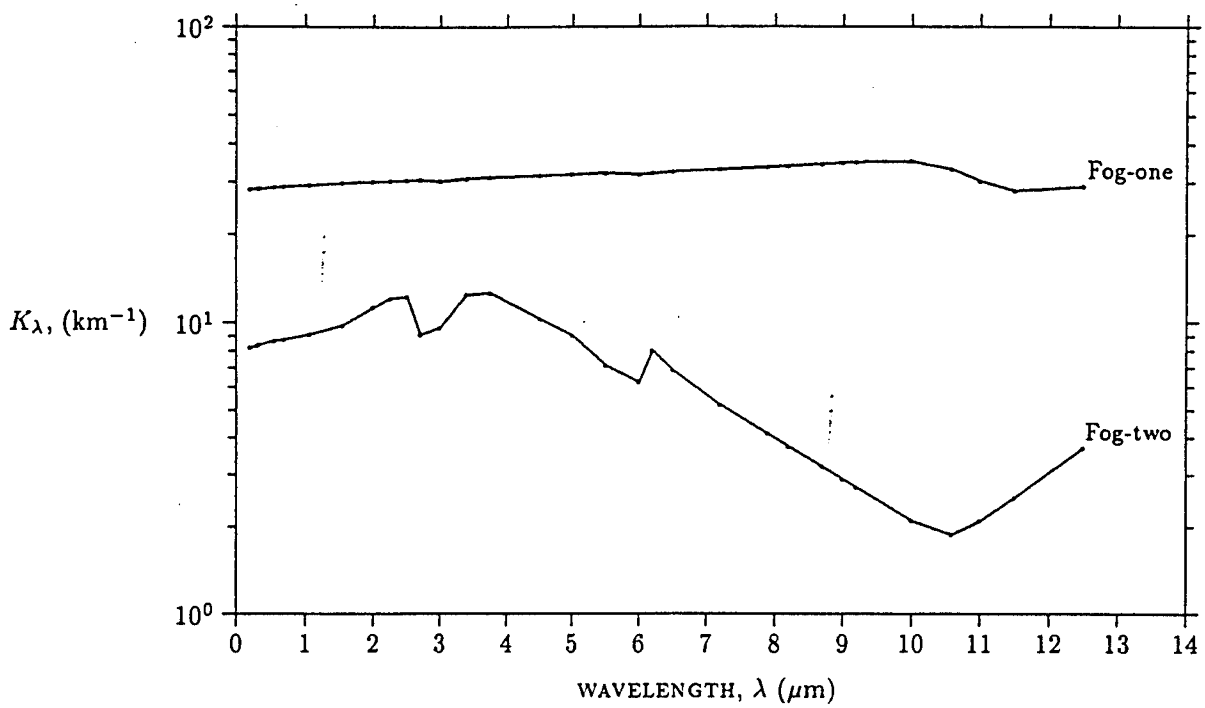

Figure 8. Fog-one and fog-two extinction as a function of wavelength. Fog-one density is 20 particles/cm³; fog-two density is 200 particles/cm³. Semilog scale used.

2.1.3 Desert Aerosol

This release of XSCALE includes a desert aerosol model. [11] This model arises from measurements taken in northern Africa and the southwest United States between 1977 and 1985. Several measurement efforts were examined. The measurements included size distributions, composition, radiation, and total mass loading. Usually, any one effort involved only one type of measurement. [11] As implemented within XSCALE, the desert air mass is composed of three components; each component has a different log normal (equation (2)), particle size distribution, and indices of refraction. The components represent carbonaceous particles, water soluble particles, and sand. Two types of sand contribute to the sand component; 50 percent of sand particles are pure quartz and 50 percent are quartz contaminated with 10 percent hematite. The amount of carbonaceous and water soluble particles are constant (once they are scaled by the visibility); the sand component increases with wind speed. This model does not consider a humidity dependence. An example of the

particle size distribution is shown in figure 9. The densities of the components are arbitrary, but are roughly similar to those measured before. [11] The mode radii, standard deviations, and densities used are given in table 2.

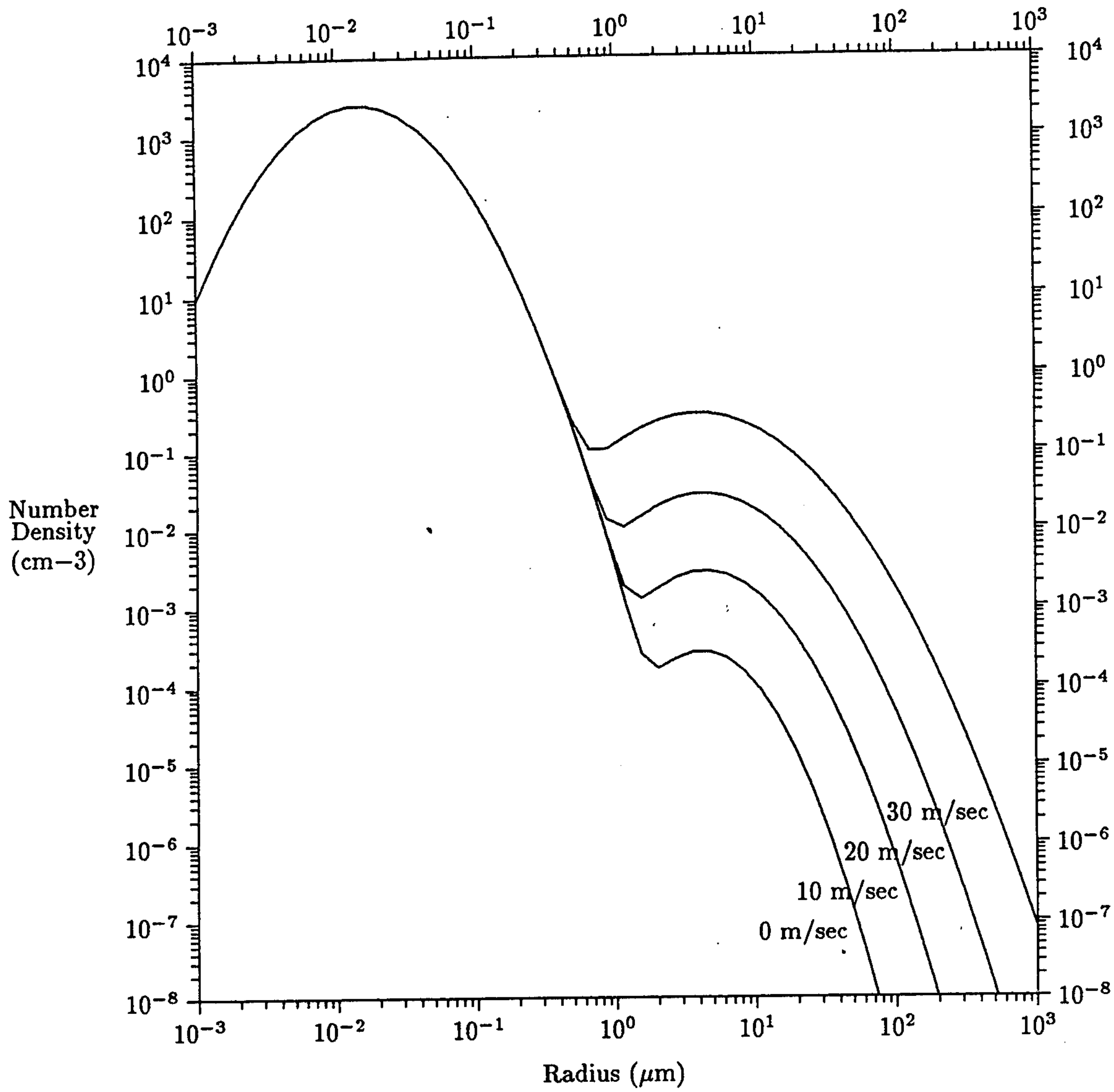

Figure 9. Desert particle size distribution at four wind speeds: 0, 10, 20, and 30 m/s. Arbitrary particle densities, see table 2.

A look-up table is contained within the XSCALE module. Relative extinction and absorption coefficients normalized to the extinction at 0.55 μm are tabulated at 31 wavelengths and 4 wind speeds. XSCALE performs linear interpolation to determine the relative extinction, absorption, and scattering coefficients at any specific wavelength and

wind speed; these are scaled by the visibility. Figure 10 shows the extinction coefficient as a function of wavelength at the four wind speeds. For a constant background air mass, the mass loading increases with wind speed. The figure 10 plots are derived from the extinction values found in appendix C of Longtin et al. [11] at the 31 wavelengths tabulated in XSCALE.

Table 2. Mode radii and standard deviations of the XSCALE aerosols. The standard deviation values are appropriate for the Shettle-Fenn particle size distribution of equation (2)

Wind	Carbonaceous			Water Soluble			Sand		
Speed	N_1	r_1	σ_1	N_2	r_2	σ_2	N_3	r_3	σ_3
(m/s)	(cm^{-3})	(μm)	—	(cm^{-3})	(μm)	—	(cm^{-3})	(μm)	—
0	0.3197	0.0118	2.00	682.0	0.0285	2.24	0.0152	6.24	1.89
10	0.3197	0.0118	2.00	682.0	0.0285	2.24	0.2022	7.76	2.14
20	0.3197	0.0118	2.00	682.0	0.0285	2.24	2.402	9.28	2.42
30	0.3197	0.0118	2.00	682.0	0.0285	2.24	30.55	10.80	2.74

2.1.4 Attenuation Through Rain

The attenuation in the visible and IR range caused by raindrops can be calculated by means of the Mie theory. [6] The attenuation can be expressed as a function of rain rate. Visible and IR wavelengths are significantly less than the radius of most raindrops, which typically vary from 50 μm to a few mm. Thus, the XSCALE model assumes a value of 2 for the Mie extinction coefficient. This removes the wavelength dependence of the extinction coefficient in this band of the electromagnetic spectrum, resulting in an extinction coefficient:

$$K = 2\pi \int N(r)\ r^2\ dr, \tag{8}$$

where

N(r) = the rain particle size distribution.

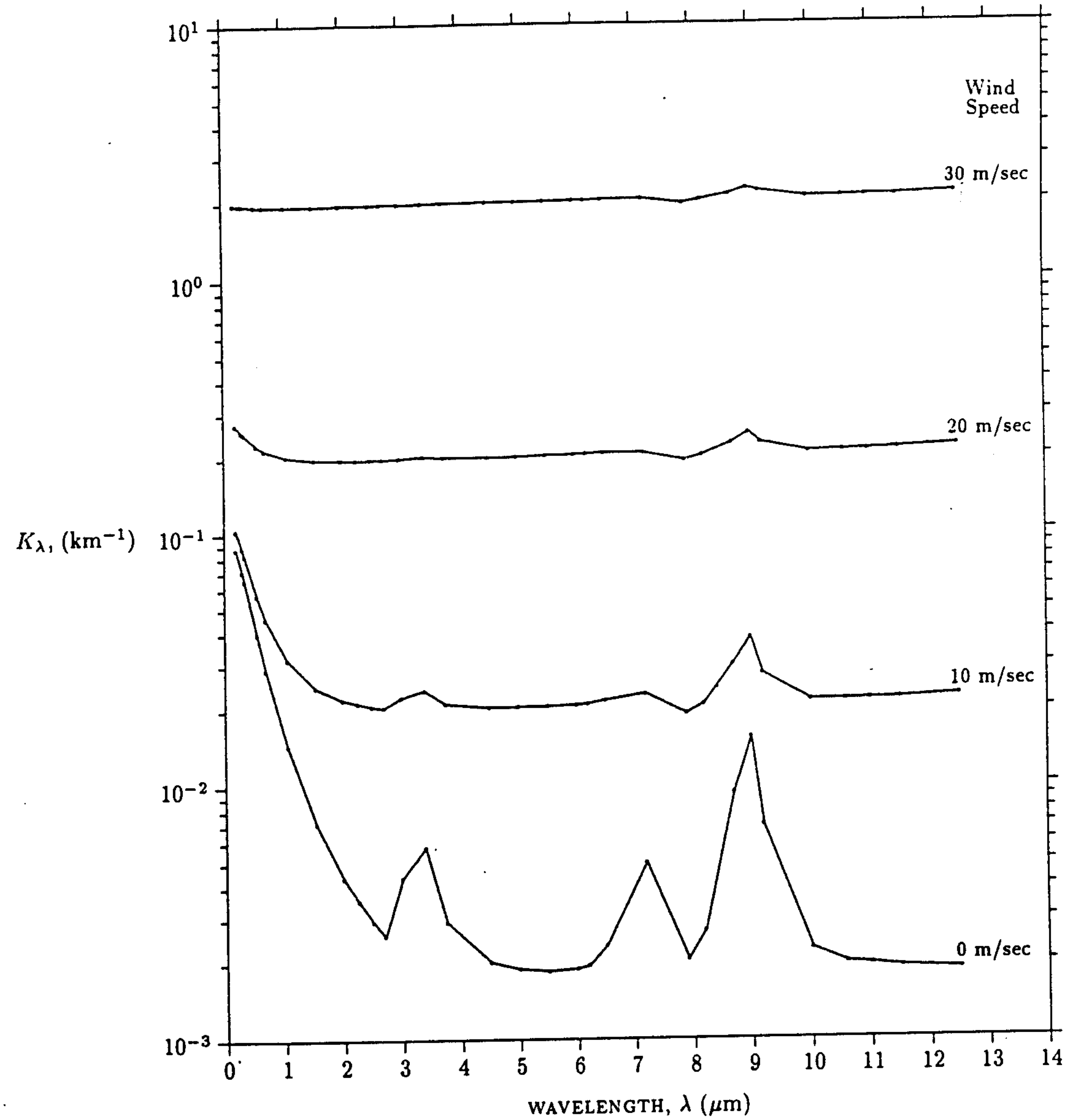

Figure 10. Desert extinction as a function of wavelength and wind speed. Semilog scale used.

Several different models for raindrop size distributions are found in the literature. The most widely used description is that of Marshall and Palmer, [12] which is based on the observations of Laws and Parsons. [13] This distribution is given by the following:

$$N(d) = N_o \exp(-\Lambda d), \tag{9}$$

where

Λ = $4.1R^{-0.21}$ (mm^{-1})
N_o = 8×10^3 ($m^{-3}\ mm^{-1}$)
d = the droplet diameter (mm)
R = the rain rate (mm/h).

With this distribution, the extinction coefficient in km^{-1} can be expressed as a function of rain rate:

$$K = 0.365\ R^{0.63}. \tag{10}$$

The data of Waldvogel [14] shows that different size distributions are typical of different rain situations. Joss and Waldvogel developed size distributions for drizzle, widespread rain, and thunderstorm situations. [15] For these three models, the extinction coefficient is related to rain rate by the following:

$$K = 0.5089\ R^{0.63}, \text{ drizzle} \tag{11}$$

$$K = 0.3201\ R^{0.63}, \text{ widespread rain,} \tag{12}$$

$$K = 0.1635\ R^{0.63}, \text{ thunderstorm.} \tag{13}$$

Equations (10) and (12) show that the Marshall and Palmer distribution and the Joss and Waldvogel model for widespread rain give comparable values for extinction.

Equations (11), (12), and (13) are used as the XSCALE rain models. Equation (12) is recommended for general use and is the default model of the computer code if a specific model is not requested. The other two models may be used to provide reasonable upper and lower bounds for the extinction coefficient for a given rain rate, or to investigate the type of rainfall they represent. Table 3 gives representative rain rates for the three types of rain; the default is 3 mm/h.

Table 3. Rain, type, and rate

Rainfall Type	Rate (mm/h)
Drizzle	$R \leq 1.00$
Widespread rain	$1.00 < R \leq 7.60$
Thunderstorm	$7.60 < R$

2.1.5 *Attenuation Through Falling Snow*

Falling snow is defined in XSCALE as precipitating snow carried by a wind of less than 5 m/s and a relative humidity of less than 95 percent. Crystals of falling snow generally are large, 100 µm or more, in comparison to visible and IR wavelengths. The geometric optics approximation are expected to be valid. Therefore, the extinction coefficient is equal to 2.0 and the resulting extinction is wavelength independent. However, field measurements of transmittance usually have exhibited a wavelength dependence in falling snow such that the extinction coefficient increases with wavelength in the absence of coexisting fog. This observed spectral dependence is explained for the most part by considering diffraction effects. For the above conditions, the forward direction diffraction lobe is very narrow at visible wavelengths, but increases in width with wavelength. Thus, as the wavelength increases, less diffracted energy is directed along the LOS to enter the transmissometer resulting in an increasing extinction coefficient with wavelength.

The diffracted energy entering a detector may be used to develop an approximate relationship to calculate radiative transfer in snow and to give the functional dependence of the spectral variations in extinction on path length L, detector radius r_d, and snow particle size $\bar{r}$: [16]

$$\frac{K(\lambda_1)}{K(\lambda_2)} = \frac{\exp(-0.88\ C(\lambda_1)) + 1}{\exp(-0.88\ C(\lambda_2)) + 1}, \tag{14}$$

where the subscripts indicate values corresponding to two different wavelengths, path lengths, detector radii, or particle size. The C_i are given by the following:

$$C(\lambda_i) = 2\pi\ \bar{r}\ \frac{r_{d_i}}{\lambda_i L_i}. \tag{15}$$

If the detector radius is small in comparison to the path length, $K(\lambda_1) \approx K(\lambda_2)$.

An approximate value of $\bar{r}$ for a particular snow particle size distribution must be determined. If the size distribution is approximately known, then a value of $\bar{r}$ equal to one-half the distribution model radius or one-tenth the maximum radius would be appropriate. The XSCALE inputs do not allow for entering of $\bar{r}$, the subroutine XSCALE would need to be modified. A second method of estimating $\bar{r}$, which XSCALE uses, is to assume it to be a function of surface temperature T, based on the observations that warmer snow fall generally is larger:

$$\bar{r} = \begin{cases} 100\ \mu m & T \le -15\ ^\circ C \\ (250 + 10T)\ \mu m & -15\ ^\circ C < T < 0\ ^\circ C \\ (250 + 25T)\ \mu m & -0\ ^\circ C \le T \le 2\ ^\circ C \\ 300\ \mu m & T > 2\ ^\circ C \end{cases} \tag{16}$$

The extinction coefficient at wavelength λ as a function of visibility V may be obtained from equation (14) with r_d and L fixed:

$$K(\lambda) = \frac{\exp(-0.88 \ C(\lambda)) + 1}{\exp(-0.88 \ C(0.55 \ \mu m)) + 1} \cdot \frac{3.912}{V}, \qquad (17)$$

where $C(\lambda)$ and $C(0.55\ \mu m)$ are given by equation (15).* If path radiance effects are ignored and if diffraction effects are neglected in human visibility cases, then for $C(0.55\ \mu m)$ in equation (15), r_d is 0.2 cm, $\lambda = 0.55\ \mu m$, and $\bar{r}/L$ is small. Thus $C(0.55\ \mu m)$ is small, the denominator exponential approaches 1, and the denominator of the first fraction approaches 2, giving the following:

$$K(\lambda) = [\exp - \ (0.88 \ C(\lambda)) + 1] \ \frac{1.96}{V}. \qquad (18)$$

XSCALE employs equation (17). Equation (15) is convenient for hand approximations.

2.1.6 *Attenuation Through Blowing Snow*

Blowing snow is defined for XSCALE as snow carried by a wind of speed greater than 5 m/s and a relative humidity less than 95 percent. The spectral dependence of extinction in blowing snow and the relationship between visibility and the extinction coefficient are determined by equation (17). The particle sizes of blowing snow generally are small than for falling snow, and a value of 100 µm or less for $\bar{r}$ is appropriate.†

**In equation (17), there is no explicit dependence on precipitation rate; this enters the equation through the visibility estimate.*

†Visibility in blowing snow as a function of wind speed is: [17] $V = a\ u^{-5}$, where $a = 1.1 \times 10^8\ m^6\ s^{-5}$ for unlimited loose snow on the surface and $a = 10^{10}\ m^6\ s^{-5}$ for very little available snow. The V may be approximated only if the wind speed is known; however, a varies over two orders of magnitude.

2.1.7 *Attenuation Through Snow and Fog*

XSCALE defines snow and fog to be falling snow occurring with a relative humidity greater than 95 percent; no height variation is considered. The total extinction coefficient K_λ, in the combination of snow and fog, is equal to the sum of the extinction coefficient for fog alone plus that of snow alone. Therefore, if $0 \le B \le 1$ is the fraction of the total extinction caused by snow, then

$$K(\lambda) = (1 - B)\, K_{F\lambda} + BK_{S\lambda}, \tag{19}$$

where

$K_{F\lambda}$ = the fog extinction coefficient
$K_{S\lambda}$ = the snow extinction coefficient

under the current conditions.

The fraction B is estimated within XSCALE by a calculation based on a regression equation obtained from analysis of the Scenario Normalization for Operations in Winter (SNOW) series field experiment data: [18]

$$B = -0.025T + 0.23V^{-1} - 0.021H + 2.47, \tag{20}$$

where

T = the temperature in °C at 2 m
V = the visibility in km
H = the percent relative humidity at 2 m.

This equation does not give completely accurate values for B since relative amounts of snow and fog are weakly correlated with temperature, visibility, and relative humidity.

With the scaling laws given above for snow and the interpolation described in section 2.1.1 for fog, equation (19) is used by XSCALE to calculate $K\lambda$ at various wavelengths when it is known at one wavelength.

2.1.8 *Attenuation Through Ice Fog*

Ice fog forms when a hot combustion by-product, such as automobile exhaust or a heating flue gas, enters a cold air mass of less than -30 °C. Rapid cooling produces a supersaturated mixture from which water droplets condense, freeze into ice fog particles, and grow until the vapor is exhausted. Because combustion is a good source of vapor and nucleating material, ice fog is common in populated arctic and subarctic areas. Ice fog also forms over open water, such as cooling ponds and hot springs, although the process is slower and fewer particles result.

Attenuation through ice fog is calculated by the Mie theory. [6] Since the heaviest concentrations of ice fog contain mostly irregular, nuggetlike particles, sphericity is a reasonable approximation. Although various size distributions can describe ice fog particles, for ease of computation, a Maxwell function is used for the following form: [19]

$$N(r) = \frac{4N_o}{r_c^3 \sqrt{\pi}} r^2 \exp\left[-\left(\frac{r}{r_c}\right)^2\right], \tag{21}$$

where

$N(r)$ = the particle size distribution
N_0 = the total particle concentration
r_c = the mode radius.

Particles range from about 1 to 20 μm in diameter; they increase in size with ambient air temperature and decrease with the temperature of the water vapor source. [20,21] Distributions frequently are multimodal, hypothetically caused by different vapor sources. The user may supply a mix of up to three components for the distribution; or XSCALE will default to one of the two combinations of table 4, depending on whether open water is present.*

**These distributions are representative of those sampled by Huffman. [21]*

Table 4. XSCALE multimodal ice fog particle size distribution

Proportion of particles	Open water nearby	No open water nearby	Vapor source
p_1	0.42	0.56	automobile exhaust
p_2	0.33	0.44	heating flue gases
p_3	0.25	0.00	open water
Total	1.00	1.00	

Values for r_c are input or estimated by XSCALE as follows: [22]

$$r_c = \begin{cases} \exp(-27.51 + 0.120T_k) & \text{automobile exhaust} \\ \exp(-26.87 + 0.119T_k) & \text{heating flue gases} \\ \exp(-26.12 + 0.118T_k) & \text{open water}^* \end{cases} \tag{22}$$

In the above, T_k is the ambient air temperature in Kelvin.

The extinction efficiency Q_λ for ice fog is very sensitive to particle size, wavelength λ, and refractive index m. For a collection of particles with mode radius r_c and a combined geometrical cross section of $N_0 \pi r_c^2$, $Q\lambda$ is described by the following theoretical formulae, valid for the indicated ranges of $x_c \equiv 2\pi r_c/\lambda$ or $\rho_c \equiv 2(m-1)x_c$, where $m \equiv n - in'$.

In Rayleigh scattering region $(x_c \le 0.81 - 3n'(\sqrt{n} - 1))$,

$$Q\lambda = -\Im m\left[\frac{16}{\pi}x_c P + \frac{3.2}{\sqrt{\pi}}x_c^3 \ P^2 \ \frac{m^4 + 27m^2 + 38}{2m^2 + 3}\right] + \Re e\left[35x_c^4 \ P^2 - 56x_c^6 \ P^2 \ \frac{1}{m^2}\right], \tag{23}$$

where $P = \dfrac{m^2 - 1}{m^2 + 2}$.

**Ohtake [20] observed that the distributions of particle radii from unpolluted open water sources (hot springs) have narrow peaks in concentration at around 5 µm.*

In intermediate ρ_c ($x_c > 0.81 - 3n' (\sqrt{n} - 1)$; $\Re e(\rho_c)$ or $\Im m(\rho_c) \leq 4.0$),

$$Q\lambda = 3 + \frac{5.5}{C}\left(1 - \exp(-\frac{0.44C}{x_c^{2/3}})\right) + \frac{4m}{\rho_c^2}\left[1 - \left(1 + \rho_c^2 - \frac{\rho_c^4}{4}\right)\exp(-\frac{\rho_c^2}{2})\ \mathrm{erfc}(i\frac{\rho_c}{2})\right] - i\frac{4m}{\rho_c\sqrt{\pi}} + i\frac{2m\rho_c}{\sqrt{\pi}}, \tag{24}$$

where $C = m\dfrac{m + 1}{m - 1}$.

Large ρ_c region ($\Re e(\rho_c)$ or $\Im m(\rho_c) > 4.0$)

$$Q\lambda = 3 + \frac{2.442}{x_c^{2/3}} - \Im m\left\{\frac{2.257}{x_c}\left[\frac{m^2 + 1}{\sqrt{m^2 - 1}}\right] - \frac{0.759}{x_c^{4/3}} + \frac{4m}{\rho_c^2}\right\}. \tag{25}$$

Indices of refraction are supplied within XSCALE from a table compiled by Warren. [23] The function $\exp(-\rho_c^2 / 2)\ \mathrm{erfc}(i\ \rho_c / 2)$ is approximated to an accuracy of ± 0.01 by equations derived through the method of continued fractions. [24] Except near the boundary between the Rayleigh and intermediate ρ_c regions where errors may run to ± 20 percent*, these formulae estimate $Q\lambda$ to within ± 4 percent of the rigorous Mie solutions. The combined extinction Q_{avg} for all vapor sources is calculated as a weighted average:

$$Q_{avg} = \sum_{i=1}^{3} \rho_i Q_i. \tag{26}$$

**Errors of ± 10 to 20 percent are limited to a relatively narrow region around $x_c = 0.81 - 3n'(\sqrt{n} - 1) \pm 0.1$, and will be considerably lessened by broadband averaging.*

The extinction coefficient $K\lambda$ for ice fog with visibility V is as follows:

$$K\lambda = \left(\frac{Q_{\lambda,\ avg}}{Q_{0.55,\ avg}} \right) \frac{3.912}{V}, \tag{27}$$

where $Q_{0.55,\ avg}$ is found by evaluating equations (23), (24), or (25) for $m = 1.311$ and $\lambda = 0.55$.

2.2 Attenuation Along Inclined Lines of Sight

2.2.1 Introduction

The development of precision guided munitions and sophisticated EO sensors have placed new emphasis on near surface visibility. Traditionally, visibility has referred to visual estimates of the range within which certain objects were discernible against the horizon or background. Often the visibility estimates were automatically measured and recorded by several types of visibility meters. In either case, the emphasis has been upon the horizontal visibility. New surveillance and weapon systems are increasingly relying on sensors that must function over a slant path, where variations in the vertical as well as the horizontal visibility are important.

In low visibility situations, because of haze or fog, a large number of observations have shown that the measured visibility at the surface is not representative of conditions a few hundred meters, or even tens of meters, above the surface. [3,4,5,25,26,27,28] Therefore, slant path visibility can be significantly different from horizontal visibility. In a significant fraction of the cases, the visibility becomes worse as the height above the surface increases. These cases are of special concern here. [29,30] This part of XSCALE is controlled by the subroutine `SLANT`. The extinction and absorption tables for hazes and fogs described above and semi-empirical formulae for visible extinction and relative humidity profiles are used to predict the IR extinction as a function of height. Extinction within a low lying stratus cloud is modeled by the fog-one particle size distribution.

The transmittance over a path of varying extinction is obtained by using the average extinction along the path in equation (1). The average extinction is the path integral of the extinction along the path divided by the path length:

$$\overline{K} = \frac{1}{S}\int_{s_i}^{s_f} K(s)\ ds, \tag{28}$$

where

s = the spatial path
S = $s_f - s_i$.

If z is the vertical displacement of the path ($Z = z_f - z_i$) and θ the elevation angle, then ds can be written as ds = dz/sin θ = S dz/Z (sin θ = Z/S). Since K depends only on altitude, K(s) = K(z). See figure 11 for the geometry. Therefore, $\overline{K}$ can be rewritten in terms of altitude:

$$\overline{K} = \frac{1}{S}\ \frac{S}{Z}\int_{z_i}^{z_f} K(z)\ dz = \frac{1}{Z}\int_{z_i}^{z_f} K(z)\ dz. \tag{29}$$

XSCALE approximates this integration by the sum

$$\overline{K} = \frac{1}{Z}\sum_{i=1}^{N-1}\frac{K_i + K_{i+1}}{2}\ (z_{i+1} - z_i) \tag{30}$$

for N points along the path.

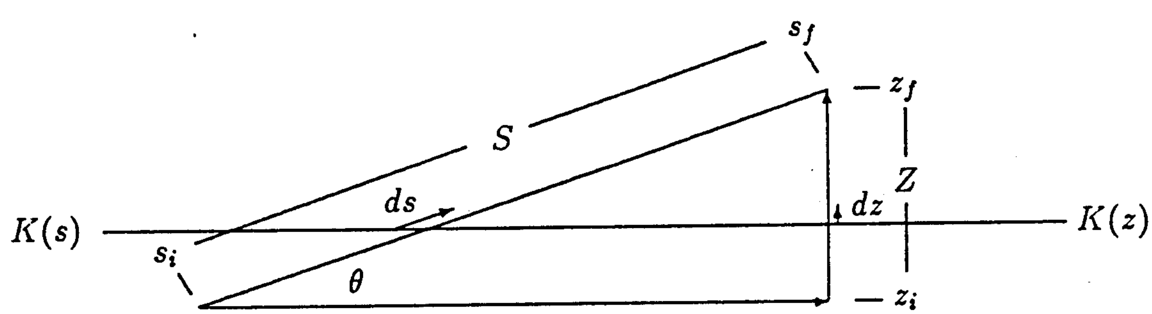

Figure 11. Slant path geometry.

The vertical profile of the extinction of blowing snow has been implemented in this version of XSCALE. The model is discussed in the final subsection of this section. The subroutine SNOSLN contains the Fortran code for this model.

2.2.2 *Basis of Vertical Profile Model*

Detailed data on the vertical structure of fogs and hazes has been gathered in the United Kingdom and the Federal Republic of Germany on several occasions. [3,4,5,25,28] Droplet size distributions in the 0.5- to 47-μm range have been measured from a balloon borne instrument, thus yielding vertical profiles. Extinction coefficients at desired wavelengths or the liquid water content can be calculated from these measured droplet size distributions.

Duncan and others [31] have examined the vertical structure of these profiles previously and have characterized the vertical structure in the form:

$$y = a'x + b', \tag{31}$$

where

x	=	$\log_{10}[K_{0.55}(z)]$
y	=	$\log_{10}[K_{0.55}(z+20)]$
a' and b'	=	the coefficients that were chosen to fit the data
$K_{0.55}(z)$	=	the value of the visible extinction coefficient at altitude z
$K_{0.55}(z+20)$	=	value of this variable at an altitude of $z + 20$ m.

Thus, the work is accomplished stepwise from the surface up through the cloud boundary layer. Since $x = \log_{10}[K_{0.55}(z)]$ in equation (31) and y is $x + \Delta x$, a relation for the extinction as a function of altitude can be derived as follows: [29]

$$K_{0.55}(z) = A \exp[B \exp(Cz)], \tag{32}$$

where A, B, and C are functions of the boundary conditions, such as the ground level value of extinction, and the cloud ceiling height. Note that

the coefficients A, B, and C may have different values, depending on whether one is below or within a low-lying stratus cloud.

The original development of the vertical structure model, which resulted in equations (31) and (32), was based on data where the ceiling height was quite low, typically 300 m or less. During January and February, 1983, ASL conducted a field test at Cardington, England to obtain data for validation of the vertical structure algorithm. [5] This test provided a new block of data similar to that used to develop the vertical structure algorithm but containing measurements to altitudes of 1200 m in stratocumulus cloud conditions. When the algorithm was compared to the Cardington data, the results were found satisfactory for cases in which the ceiling was low, but much less satisfactory for the higher ceiling cases.

The comparisons showed that the vertical structure model needed to be modified to address higher ceiling situations. The success of the algorithm in describing the older data base and the part of the Cardington data with similar ceiling values requires that changes do not disturb the fit for such cases. The changes adopted are based on the idea that the farther a parcel of aerosol is below a stratus cloud, the less its properties are related to the physical details of the stratus layer itself. To be more specific, it is assumed that a critical region exists just below the stratus cloud base in which the altitude dependence of extinction is governed by the presence of the stratus. Below the critical region, the altitude dependence is less related to the presence of the stratus layer and is presumed to be similar to its value at the surface. [32] This assumption is represented in the algorithm by changing the form for the coefficient A, used in equation (32), to an empirical formula that depends on the surface visibility and cloud ceiling height (see table 5).

Table 5. Extinction equation parameters

Visible extinction, $K_{0.55}(z) = A\exp(B\exp(Cz))$					
	Units	Region 1	Region 2	Region 3	Region 4
Description		Thick fog, within cloud (ceiling obscured)	Below cloud, clear/haze/light fog at surface. Ceiling less than 2 km	Inversion layer, radiation fog, no ceiling or greater than 2 km	Clear sky, no or high ceiling, no distinct layer.
Aerosol type		Fog-one aerosol	Maritime, Urban, Rural, or Fog-two may be selected.		
Surface visibility, V	km	less than 0.5	$0.56 < V < 50.0$		$0.56 < V < 326.$
Surface extinction, D, $K_{0.55}(0)$	km^{-1}	greater than 7	$0.0782 < D < 7.0$		$0.012 < D < 7.$
Parameter A B C	 km^{-1} none m^{-1}	 92.0 Note a $\ln(D/A)$ -0.014 Note a $B < 0, C < 0$	 $F(1 - e^{-D/F})$ $\ln(D/A)$ $\frac{1}{Z_c} * \ln(\frac{\ln(7.0/A)}{B})$ Note a $B > 0, C > 0$	 $1.1 * D$ Note b $\ln(D/A)$ $\frac{1}{Z_c} * \ln(\frac{\ln(0.0782/A)}{B})$ Note c $B < 0, C > 0$	 0.012 Note c $\ln(D/A)$ -0.030 Note b $B > 0$ (if $V < 326$, i.e., the Rayleigh limit), $C < 0$
Associated parameter F Z_c	 km^2 m		 $\left(\frac{VZ_c}{350}\right)^2$ Note d CEILHT, cloud ceiling height Note e	 AINVHT, inversion layer thickness	
Region selected by:		IAERO = 4 or D > 7 or $V \leq 0.2$ km and IAERO = 5 $\Longrightarrow$ IAERO = 4	D $\leq$ 7 and CEILHT > 0	CEILHT < 0 and AINVHT $\geq$ 0 or IAERO = 5	CEILHT < 0 and AINVHT < 0
Defaults:		if THICK $\leq$ 0 then THICK = 0.1 km		if AINVHT = 0 AINVHT = 0.1 km	None

D = visible extinction at surface in km^{-1}, $= \frac{3.912}{V} - 0.012$ (in region 1 for the path within a cloud $D = 7$),
in VSA this is the FORTRAN variable D.

Z_c = cloud ceiling or inversion layer height in m.
in VSA this is the FORTRAN variable CEILHT or AINVHT.

FORTRAN variables not defined elsewhere:

THICK is the thickness of the cloud or fog layer.

IAERO is the selected aerosol type, type 5 is the fog-two aerosol.

Notes:

a. Value of coefficient based upon data representative of low-lying stratus clouds.
b. Ad-hoc default value; insufficient data to determine best value. May be adjusted by users.
c. Value of coefficient chosen to represent "clear atmosphere" background above surface layer.
d. Empirically determined scaling factor to best fit the data.
e. A solid (8/8's) cloud cover is assumed.

2.2.3 *Parameterization of the Model*

XSCALE uses four different regions to model a vertical extinction profile. In this subsection, the regions will be described and the circumstances in which they apply. Once a region has been associated with an atmospheric layer, the values of the coefficients A, B, and C in equation (32) can be found for that layer.

The division between regions 1 and 2 (see figure 12) physically represents the change in extinction due to changes in the state of particle growth as one moves from a subsaturated environment (region 2), where relative humidities are less than 100 percent, to a supersaturated environment (region 1). Thus, this division will be taken to represent the cloud boundary. Region 1 represents the change in extinction with altitude caused by a growing and changing particle-size distribution in a moist, supersaturated environment. This environment is that of a stratus cloud or a thick, ground-based fog where droplet size distributions are being controlled by convective motions. The upper boundary for the extinction represents the average upper limit expected for the extinction in a stratus cloud or thick fog.

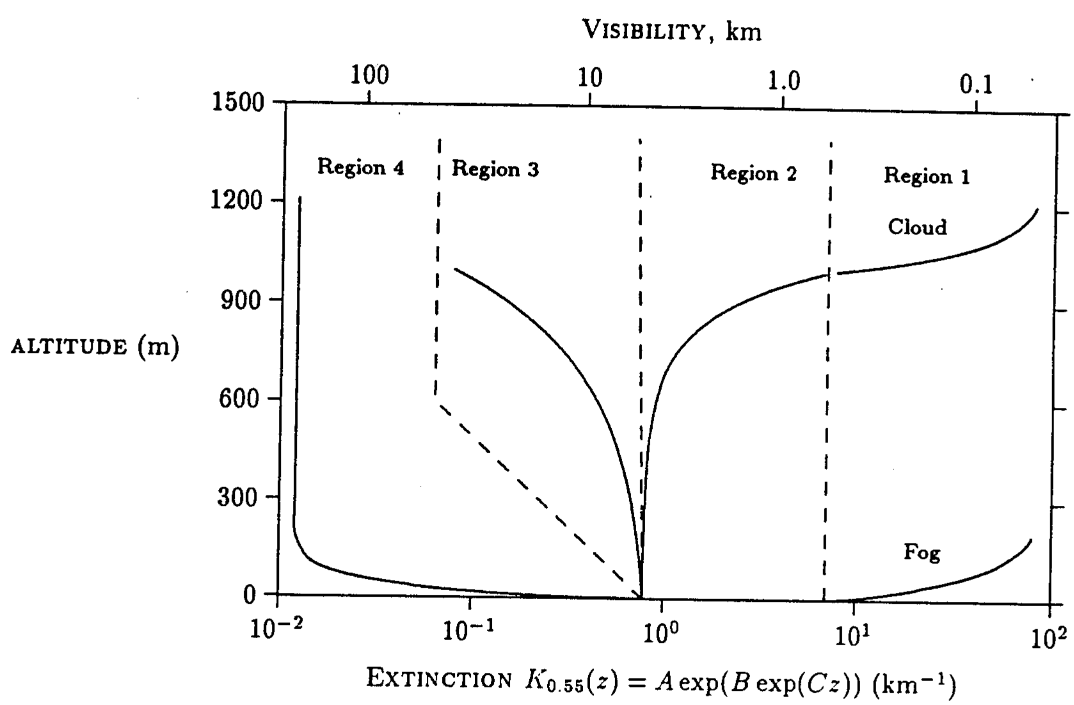

Figure 12. Four regions represented by the vertical structure algorithm.

Region 2 represents the change in extinction with altitude below the cloud boundary. The coefficients A, B, and C represent the increase in extinction caused by particle-size distribution growth changes in a clear to foggy layer beneath a cloud.

The rate at which the extinction changes with altitude below the cloud ceiling depends on the cloud ceiling height Z_c. The explicit dependence of C on the cloud ceiling height can be incorporated by defining the coefficient C as follows:

$$C = \frac{1}{Z_c} \ln\left[\frac{\ln(E/A)}{\ln(D/A)}\right], \tag{33}$$

where

Z_c = the cloud ceiling height
E = the value for the extinction at the cloud base
D = the value of 0.55 μm extinction at the surface.

A is explained in greater detail below. In practice, E has the value 7 km^{-1}, and D can be calculated from the surface visibility V by using equation (4).

Originally, the algorithm for the vertical structure of hazes, fogs and clouds represented by equation (32) was developed for low visibility and low stratus conditions in which the extinction increases with altitude. This algorithm is based on inputs of the surface meteorological range (extinction coefficient) and the cloud ceiling height. This algorithm has been extended to regions 3 and 4 where there may be no cloud ceiling and the extinction coefficient decreases with increasing altitude.

One additional parameter is needed for use with the vertical structure algorithms — the value of the relative humidity (H) as a function of altitude up to the cloud ceiling (assumed to be at 100 percent relative humidity). Within a cloud or fog, the relative humidity is set equal to 100 percent. When the path is below the cloud deck (where visibility can vary from clear to foggy conditions), the following empirically derived algorithm is used:

$$H(z) = a \ln K_{0.55}(z) + b. \tag{34}$$

Equation (35) is a restatement of the reaction between visibility and relative humidity found in Shettle and Fenn and Hanel. [1,2] The coefficients a and b are adjusted to represent the change in relative humidity with altitude from the surface (H_o) to the cloud base (H = 100 percent):

$$a = \frac{100 - H_o}{\ln(7 / D)} \tag{35}$$

$$b = 100 - a \ln(7) \tag{36}$$

D is the same initial value of the extinction coefficient at the surface as used in equation (33).

2.2.4 *Use of the Vertical Profile Model*

Depending on the signs of the coefficients B and C in equation (32), the vertical structure of visibility can be represented by four different curves as illustrated in figure 12. Curves 1 and 2 represent the regions where the extinction coefficient increases (visibility degrades) with increasing altitude; these regions represent the vertical structure of extinction for low visibility and low stratus conditions and for dense fog at the surface, or when inside the cloud. Curves 3 and 4 represent regions where the extinction coefficient decreases (visibility improves) with increasing altitude. Each of these regions are:

Region 1: ($B < 0$, $C < 0$) A is the upper limit for the extinction coefficient in the thick fog and cloud layer. This curve is to be used for dense fogs at ground level, at the cloud base, or in the cloud. Physically, this curve represents the increase in liquid water content, and consequently, the increase in extinction coefficient and decrease in visibility of a saturated parcel of air rising at the wet adiabatic lapse rate. [29, 33] This curve should be used only when the extinction coefficient (or meteorological range) is in the thick fog and cloud layer (i.e., $K_{0.55} > 7$ km^{-1}).

Region 2: ($B > 0$, $C > 0$) A is the lower limit for extinction coefficient in clear to foggy conditions at the surface. This curve is to be used for

visibility conditions ranging from clear to hazy to light fog when there is a low cloud ceiling present.

Region 3: ($B < 0$, $C > 0$) A is the upper limit for the extinction coefficient. Surface visibility should indicate clear, hazy, or light fog conditions. This curve is to be used when there is a shallow radiation fog present or when a haze layer is capped by a distinct, low-lying temperature inversion. A cloud ceiling is not present.

Region 4: ($B > 0$, $C < 0$) A is the lower limit for the extinction coefficient and is taken as the nominal background value within the planetary boundary layer. This profile is used for regions of reasonable vertical homogeneity of visibility in a clear to slightly hazy atmosphere that may have a shallow haze layer near the surface. A cloud ceiling is not present.

Profiles of the 0.55 μm extinction coefficient are shown in figure 12 for these different regions. Two examples of representative profiles are shown for region 1. The first example is for a thick fog at the surface, which is represented by an extinction coefficient profile that increases with height. When the depth of the fog is not known (usually the case because the sky is obscured), a default depth of 100 m is recommended. The second example is for a low-lying stratus cloud; for illustration, the cloud ceiling height is taken to be 1000 m. As shown, this is an extension of the region 2 below-cloud profile into a cloud. This region 1 profile should only be used from the cloud base to the cloud top. Again, cloud thickness is usually not a measured quantity, and a default value of 100 m is recommended. Within the thick fog and cloud layer, only profiles of the region 1 type should be used. For a dense, shallow radiation fog, use region 3 as described below.

A representative profile for the structure beneath a stratus cloud of ceiling height 1000 m is shown for region 2. The slope and shape of the vertical structure profile beneath the cloud deck are a function of the initial value of the surface visibility and the cloud ceiling height. When cloud cover is present, the surface visibility may range from clear to light fog;

therefore, for any instances of ceiling height within 2000 m of the surface, a vertical structure profile similar to region 2 is appropriate.

A shallow radiation fog or a haze layer bounded by a temperature inversion can be represented by a vertical structure profile as shown in figure 12 for region 3. The boundary layer heights for such occurrences are often difficult to estimate. Temperature inversion heights can be obtained from acoustic sounders and radiosonde observations; visual sightings often can be used to estimate depths of shallow fogs or haze layers. A nominal boundary layer height of 1000 m has been selected for illustrative purposes. For radiation fogs in which the depth is not known, a default value of 100 m is selected; for inversion layers where the height of the inversion or boundary layer is not known, a default value of 100 m is selected.

Region 4 is represented by a profile for the condition in which the vertical structure is essentially constant with altitude, except for the lowest 100 m of the boundary layer. An appropriate default value is the nominal background value for the 0.55-µm extinction coefficient for a fair weather situation (represented here by a value of 0.012 km^{-1}). Numerous observations have shown that the extinction coefficient essentially is constant within the planetary layer for well-mixed conditions.

Table 5 gives the tabular values of the various coefficients that are to be used as boundary values for the different regions in their respective layers of applicability.

2.2.5 Vertical Profile of Blowing Snow

The variation of extinction with height Z for blowing snow is included in the XSCALE 92 module. The snow may originate from current precipitation, or it may be loose surface snow picked up by the wind. The surface wind speed must be greater than 5 m/s to invoke this calculation. The extinction profile is found by considering the variation of mass concentration m with height and assuming that the extinction coefficient is proportional to this m. Therefore, [34]

$$\frac{K_1}{K_2} = \frac{m_1}{m_2} = \left(\frac{Z_1}{Z_2}\right)^{-w/(ku_*)}, \tag{37}$$

where

w = particle fall velocity
k = von Karmann's constant = 0.4
u_* = friction velocity,

and the subscripts indicated values at two different heights. The friction velocity is given by the following:

$$u_* = \left[\frac{k}{\ln(h/Z_o)}\right] u_h, \tag{38}$$

where

u_h = the horizontal wind speed at height h
Z_o = the roughness height ≈ 0.1 mm for snow. [35]

The value of w is approximately 0.2 m/s for 100 μm particles. [36] Therefore, equation (37) becomes

$$\frac{K_1}{K_2} = \frac{m_1}{m_2} = \left(\frac{Z_1}{Z_2}\right)^{-(0.5/u_*)}. \tag{39}$$

This result compares favorably with the results of Seagraves: [37]

$$\frac{K_1}{K_2} = \left(\frac{Z_1}{Z_2}\right)^{-(0.596/u_*)} . \tag{40}$$

If equation (38) is rearranged for u_h, and h = 2 m,

$$u_2 = 24.7u_*, \tag{41}$$

equation (39) becomes

$$\frac{K_1}{K_2} = \left(\frac{Z_1}{Z_2}\right)^{-(12.4/u_2)} . \tag{42}$$

By identifying the subscript 1 with the altitude of interest, subscript 2 with a reference height of 2 m, and rearranging the equation, a visible extinction profile is obtained.

$$K_{0.55}(Z) = K_{0.55}(2) \left(\frac{Z}{2}\right)^{-(12.4/u_2)} . \tag{43}$$

Equation (17) may now be used to scale the visible extinction to the wavelength of interest. When the first factor of equation (17) is identified with f, and 3.912/V is recognized to be $K_{0.55}$, the extinction at λ and Z is:

$$K_\lambda = fK_{0.55}(Z) = \frac{\exp(-0.88C_\lambda) + 1}{\exp(-0.88C_{0.55}) + 1} K_{0.55}(2) \left(\frac{Z}{2}\right)^{-(12.4/u_2)} \tag{44}$$

$$= f \cdot g \cdot Z^{-a}$$

where

$a = 12.4/u_2$
$g = K_{0.55}(2)2^a$.

The path average extinction used in equation (1) is obtained by integration of equation (44):

$$K_\lambda = \frac{1}{Z_t} \int_{Z_i}^{Z_f} K_\lambda(Z)\ dZ = \frac{f\ g}{Z_t} \int_{Z_i}^{Z_f} z^{-a}\ dZ, \tag{45}$$

where

Z_f = the upper endpoint of the path
Z_i = the greater of the 2-m reference height or low end of the slant path
Z_t = $Z_f - Z_i$.

Performing the integration gives the following:

$$K_\lambda = \frac{f\ g}{Z_t(1 - a)} \left[Z_f^{(1 - a)} - Z_i^{(1 - a)}\right]. \tag{46}$$

This is the equation implemented in the subroutine SNOSLN. Because an analytic expression is used for K_λ, $K_\lambda(Z)$ for various Z are not calculated.

3. Caveats

3.1 Grade of Software

XSCALE is at the developmental grade of software (see table 6). Several evaluations have been made concentrating on the vertical structure model. Other models within XSCALE have received less scrutiny. These evaluations will be enumerated in section 3.3. As further data is collected, the models will continue to be evaluated.

Table 6. Grades of software

Research	Describes phenomena based on a physical or meteorological theory. Limited evaluations in the field or laboratory.
Developmental	Tailored version of a research model. Limits of applicability have been defined. At least several evaluations have been made.
Fieldable	Applicability has been defined. Confidence has been established throughout the community. Many evaluations have been passed. The model has been verified for its stated usage.

3.2 Model Failure

Table 7 lists the errors (fatal to the execution of the XSCALE program) for which XSCALE checks and the warnings that are printed. If one of these errors is detected, the program has not been given enough information for the calculation; execution is then returned to the EOSAEL driving program and halts. A catastrophic failure results if an input to XSCALE is incorrect and no default value can be rationally substituted. In such a case, the error flag IERR is set to 1; program execution then returns to the calling program EOEXEC which checks IERR and halts if this value is 1.

Table 7. Detectable errors

Error	Test	Action
Wavelength out of range	Initial wavelength, λ_i: $\lambda_i < 0.2$ or $12.5 < \lambda_i$ μm Final wavelength, λ_f: $\lambda_f < 0.2$ or $12.5 < \lambda_f$ μm	Control returns to EOEXEC.
Message: `***** WAVELENGTH (_____.___ UM) OUTSIDE ALLOWABLE RANGE (0.2 - 12.5) - CONTROL RETURNED TO MAIN FROM XSCALE.`		
Improper aerosol for a slant path.	For the aerosol index, $I_a \in \{1,2,3,4,5,6,7,8,9,10\}$: $I_a \in \{6,7,8,10\}$ is not allowed.	Return to EOEXEC.
Message: `INCORRECT AEROSOL TYPE FOR SLANT PATH (IAERO =___)`		
Within ICEFOG temperature too warm.	T = air temperature, $T > -30$ C	Return to XSCALE.
Message: `ICEFOG DOES NOT FORM ABOVE -30 DEGR CENT`		
Unknown input record (card).	ID = card identifier ID $\notin$ { AERO, RESF, HORZ, SLNH, SLNS, CLD, PLOT, GO , DONE, ICEF }	Return to EOEXEC.
Message: `UNKNOWN CARD TYPE - CONTROL RETURNED TO MAIN FROM XSCALE ----   --.----E----.----E----.----E----.----E----.----E----.----E----.----E--`		

XSCLIO is the subroutine responsible for input and output. Within XSCLIO, all input variables other than WAVE1 and VIS have default values assigned (see chapter 4). These defaults allow the program to run and are noted as defaults on the program output. The defaults are reasonable, but certainly not the only reasonable values; user inputs will override defaults at this level. Default values should not be depended on; values and the expected range of values should be determined for respective scenarios. XSCALE should be executed for each of these values. Users should experiment with the program to determine what difference each group of values will make.

At a lower level, within the XSCALE subroutines, checks are made of the EXT55, IAERO, RH, and TEMP. Various values are expected depending on the scenario; if an unexpected value is found, a better value is assigned and execution continues. Whenever such a change is made, a message is printed on the output file. Some of the explicit checks follow. If a fog aerosol is specified and the visibility is less than 0.2 km, fog-one is always used. If the aerosol IAERO index is greater than or equal to 6 and not equal to 10, the slant path is impossible. The desert, rain, and ice fog aerosol models do not support altitude dependent calculations. The program will not run if both an inversion height and ceiling height are input.

The program may gracefully fail in the sense that an unexpected default value is used as described in the previous two paragraphs. Such an unexpected or unwanted value amounts to a redefined scenario. The prediction for this is correct but may not be what the user intended. All XSCALE output includes the scenario parameters used in the prediction; default values are labeled as such. The output should be checked to ensure that the answer corresponds to the intended question.

The predictions made by XSCALE are realistic; a real world example can be found that will support the prediction. However, the models are empirical, and as such, the local conditions may be different from the conditions during a measurement program. Independent tests of XSCALE have shown that there are some situations that XSCALE does not model. These are noted in the following subsection as the tests are described. If possible, the predictions should be compared to a few local measurements. This can result in a useful "fudge factor" for the locale of interest.

The defaults used in XSCALE are primarily climatic averages. A transmittance prediction for a specific scenario will more likely be correct if input values for the scenario are used. Guesses are probably better than averages for a specific case. In fact, a flag can be passed to XSCALE from the EOSAEL executive program. This indicates that the CLIMAT data base has been read. Values obtained from CLIMAT will provide the default values for temperature, relative humidity, and wind speed.

Since the desert aerosol model is new to XSCALE, a few specific caveats and potential problem areas will be mentioned. This model, as implemented in XSCALE, has a fixed composition and particle size distribution. Some suggest that the aerosol composition (and therefore the particle size distribution) depends on the region where the air mass originates. [11] These factors apply to all the aerosol models, although there are probably more data and tests supporting the maritime, rural, urban, and fog aerosols. Also, despite a hygroscopic component, the desert model does not have a relative humidity dependence. The measurements apparently do not include relative humidity because of a lack of data to model; [11] it is not always true that the humidity in the desert is zero.

A corollary to the two previous points is that one usually does not know everything needed to make an accurate prediction for a specific scenario. A single XSCALE run using defaults and guesses may be useful, but consideration should also be made of runs using different values. This will provide a range of values for the transmittance to be expected in a specific scenario. With luck, the range will be small and the transmittance will be insensitive to the unknown values.

A final caveat, the single most important input value is the surface visibility. This value is used for scaling the amount of aerosol present, and the IR transmittance is some factor times the visible transmittance that is related to the visibility by equation (4). Unfortunately, the visibility is the hardest value to determine accurately. At present, the recommended solution is to run XSCALE for several representative visibility values.

3.3 Verification Tests

For the most part, XSCALE is based on empirical models. Therefore, each model has been developed to closely mimic at least one set of real world data. These data sets are cited in chapter 2 as each model is discussed. Most of the individual models have been tested against independent data sets. The rain, ice fog, and blowing snow models have not been tested nor has the slant path model for IR wavelengths. The independent tests are discussed in this chapter.

3.3.1 *Previous Tests*

A study was performed that compared the climatological average transmittance to the transmittance calculated by XSCALE using the climatological meteorology as inputs. [38] Several weather classes and regions were considered; these were taken from the CLIMAT module of EOSAEL. The XSCALE calculations compared very well to the climatological average transmittance. Since only average visible transmittance was considered, this was not a very strict test.

Measurements of the visible transmittance along the slant were compared to XSCALE predictions. [39] The predicted and measured transmittance usually corresponded to within 5 percent. However, differences of up to 15 percent were noted. XSCALE predictions generally are sensitive to the cloud ceiling height and surface visibility. Both of these values depended on a human observer. There were no instrument measurements in this test. The above similarity consequently was considered very positive.

Tower based visibility measurements to XSCALE slant path transmittance were compared in the visible. [40] For the sub-cloud case modeled by XSCALE (increasing extinction as the cloud ceiling is approached), agreement was very good. Several occurrences were noted in which the extinction decreases, but these were primarily for high clouds. XSCALE does not model this situation. Transmittance differences as large as 36 percent were found in these situations.

The Sprakensehl data set (the data set used by Hoidale [40]) was examined for the occurrence of episodes of decreasing visible extinction with height. [41] The range of measurable heights was limited to that of the tower (2 to 300 m).* These episodes predominate those of increasing extinction in high ceiling, moderate surface visibility (2 – 6 km) situations. As pointed out in the later study of Fiegel, [43] such episodes should not be thought to offer evidence against XSCALE, but to remind the

**The report of Hoidale and Schulze [42] contains the numbers of episodes in this study.*

user that XSCALE (as any model) will not model all real world situations.* The few altitudes sampled in the Sprakensehl study suggest that a thin haze layer often may occur under a cloud layer. Such an occurrence would result in constant extinction near the surface, then decreasing extinction above the haze (near the tower top). Finally, extinction would increase as the cloud is approached.

Other studies compared visible measurements of transmittance through snow and fog with XSCALE calculations. [44,45] The agreement at visible wavelengths was very good but less so at IR wavelengths. This was attributed to the off-axis forward scattering as follows: The XSCALE algorithm models the transmissometer measurement of unscattered light and that of forward scattering from snow particles near the beam (within one detector radius of the beam axis). Scattering away from the beam, entering the transmissometer will increase the transmittance (or decrease the extinction). The visible transmissometer had a beam much smaller than the receiver diameter. The IR transmissometer had a beam comparable to the receiver diameter. Off-beam scattering can enter the receiver, but the amount is not calculated by XSCALE since it is greater than one detector radius from the beam axis. The measured transmittance was reduced by the amount calculated due to off-beam scattering. This value then corresponded very well with that predicted by XSCALE. Such an adjustment has not yet been implemented in XSCALE.*

XSCALE horizontal path calculations were also compared to visible and IR transmissometer measurements through fog, haze, and rain during the BEST-ONE test. [46] Agreement was erratic. There are three reasons for the disagreement:

1. Many trials were modeled as an advection fog; only one trial had a visibility that XSCALE recognized as advection fog. If the visibility is greater than 0.55 km, a radiation fog model should be used because the advection fog particle size distribution allows too little transmittance. It should be noted that the meteorological definition

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**As a matter of course, XSCALE is driven by its users. If more fogs or the ability to hadnle multiple aerosols is required, please contact EOSAEL POC.*

of fog is: a surface visibility less than 1 km. [47] Only 2 of the 14 trials satisfy this, although fog was clearly present.

2. In only one trial does the human estimate of visibility agree with the transmissometer measured visibility. The transmissometer always measured a higher visibility than that recorded by the observer. If the transmissometer visibility were used as the XSCALE input, the agreement would improve.

3. IR extinction is sensitive to the air mass and to which air mass to employ was uncertain. All the BEST-ONE trials used in this comparison were composed of multiple aerosols: fog, drizzle, and maritime and urban haze. XSCALE does not deal with multiple aerosols.

Run predictions for each aerosol or the one aerosol of primary importance must be selected to obtain the range of possible transmittance. Gillespie did run predictions for fog and either a maritime haze or drizzle; [46] a large variation was found and neither aerosol matched the measurements.

3.3.2 *Tests Since Last User's Guide*

3.3.2.1 *Vertical profile model and Meppen IR extinction.*— Comparisons were made of the IR extinction calculated from the particle size distributions taken during three balloon flights of the Project Meppen 80 with the XSCALE vertical structure algorithm and a similarity theory model. [48] Reasonable agreement was found for visible and 3 – 5 μm transmittance; however, XSCALE greatly overestimated the 8 – 12 μm transmittance for these three profiles. These three flights make for a very limited test of the IR profile at this time.

The Project Meppen 80 balloon flight data blocks were reviewed. Thirty-three data sets, each representing one flight, and representative of low stratus or fog conditions, were examined. These data are measured particle size distributions that have been reduced and tabulated for extinction at 0.55, 1.06, and 10.6 μm as a function of altitude. XSCALE calculations were made for these profiles at the same three wavelengths. The reduced data and XSCALE results in the cloud layer were plotted for comparison; the visible and 1.06 μm profiles show very good agreement. The 10.6 μm in-cloud profiles are shown in appendix A. The agreement in

this case varies; XSCALE often overestimates the extinction, although sometimes it underestimates or gives good agreement. Figures 13, 14, and 15 consolidate all 33 comparisons onto three histograms. These histograms show the frequency distribution of the ratio of the data to model extinction for the in-cloud region at 0.55 µm (figure 13), at 1.06 µm (figure 14), and at 10.6 µm (figure 15). This extinction ratio is calculated at each altitude within the cloud and then the average of these ratios is determined for each profile; it is the average that is plotted for the frequency distribution. This ratio is near 1.0 for the 0.55 and 1.06 µm distributions, suggesting that the model and data agree. The 10.6 µm distribution shows a larger spread of values. The mean and standard deviation is 0.68 and 0.46; the median is 0.62. This suggests that XSCALE generally overestimates the 10.6 µm extinction. This is a very limited data set, made up of low, wintertime, German stratus clouds. The distribution is broad; it includes 1.0 and shows no clear peak. Since the data are limited and the disagreement neither well defined nor bad, XSCALE will not be changed at this time. A broader database or particle size distribution specifically designed for stratus clouds are needed to justify a change.

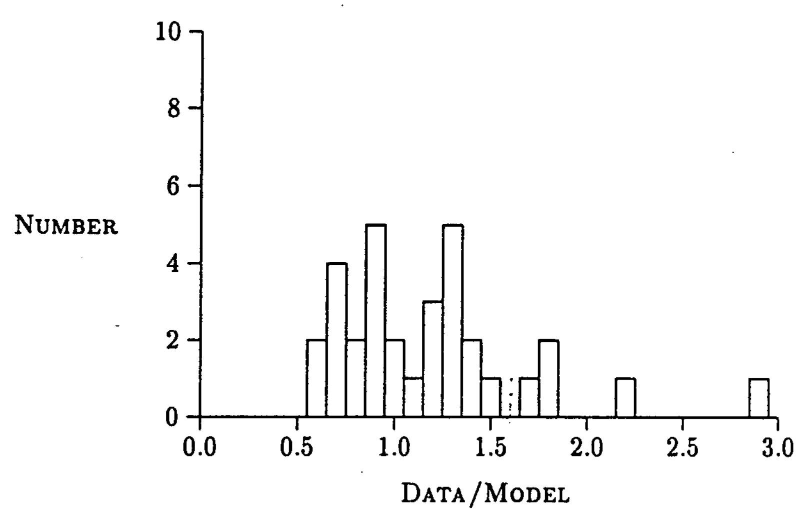


Figure 13. Data-to-model extinction ratio at 0.55 µm. Frequency distribution of the ratios of 33 profiles. The data-to-model ratio of each profile is the average of the ratios at each altitude of measurement.

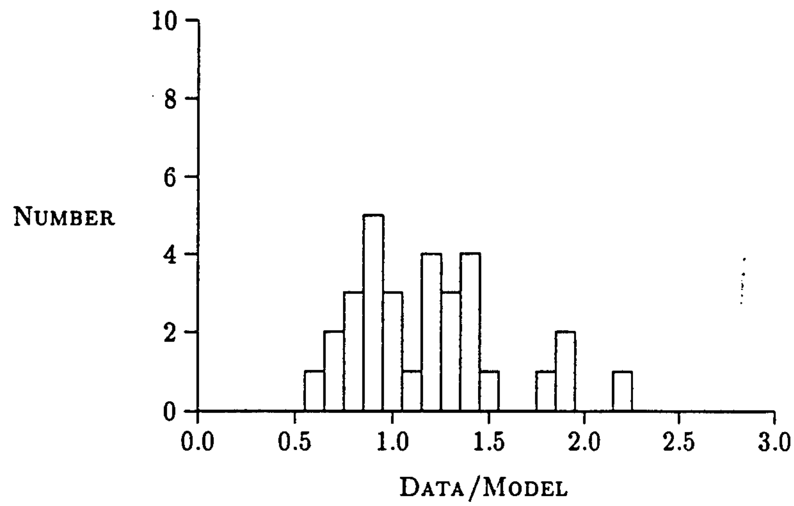


Figure 14. Data-to-model extinction ratio at 1.06 μm. Frequency distribution of the ratios of 33 profiles. The data-to-model ratio of each profile is the average of the ratios at each altitude of measurement.

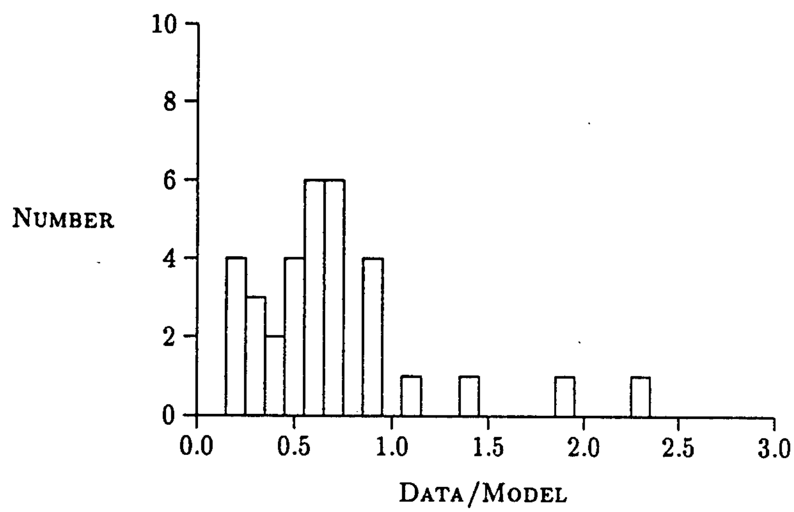


Figure 15. Data-to-model extinction ratio at 10.6 μm. Frequency distribution of the ratios of 33 profiles. The data-to-model ratio of each profile is the average of the ratios at each altitude of measurement.

3.3.2.2 Vertical profile model and Sprakensehl visible extinction.— Comparisons were made between the XSCALE visible vertical profile model and tower measurements made at Sprekensehl, Germany. [43] The data has been classified into different types of episodes. [49] An episode is a continuous span of time during which low visibility was recorded at the tower.

Episodes classified as type III.A.1 were requested from the Atmospheric Aerosol Optics Data Library (AAODL) database. [49] This classification specifies low visibility (less than 1 km) at the surface and high visibility at the top of the tower. These episodes were selected so that the tower would span the entire low visibility region and the air just above; this provides a test of the model in the overlaying clear air region as well as a test of the model in the low visibility region.

These episodes ranged in duration from 2 to 40 h; [49] the low visibility region was from 9- to 255-m thick. The data was recorded and stored as 10-min averages of the visibility, temperature, dew point, and the associated maximum and minimum measurement at each of six levels on the tower: 2, 9, 80, 150, 225, and 300 m above the ground level. A ceilometer also provided a 10-min average, maximum, and minimum measurement of the cloud ceiling. One such set of 10-min averages, maximum, and minimum values will be called a block of data.

A data block was rejected from consideration if the ceiling was measured to be greater than 300 m. In all remaining cases, the data was modeled as both an inversion layer and low cloud and fog, and the reduced chi-square was calculated. A block was said to represent an inversion layer if the reduced chi-square was less than that for the low cloud and fog case. The AAODL has 1066 blocks of data for 17 different episodes of type III.A.1. The ceilometer recorded an average ceiling less than 300 m for 733 of these blocks; the remaining blocks were not considered in this study. Of the 733 low ceiling blocks, 293 represent the XSCALE low cloud and advection fog profile, and 119 represent the inversion and radiation fog profile. The remaining 321 blocks are not well modeled by the current version of XSCALE.

The vertical extinction profile depends on the following inputs: ceiling height, cloud thickness, and inversion height. The profile also depends on the value of surface extinction. During analyses of these data, the clear

air value for the extinction (0.031 km^{-1}) above the low visibility region was also a model input. The ceiling height is the altitude at which the extinction first increases to 7 km^{-1}, or 0 m if the surface extinction is greater than 7 km^{-1}. This altitude is calculated by linear interpolation between the data points. Surface extinction and the upper air extinction are 2 and 300 m, respectively. The cloud top and inversion layer heights were determined to minimize the subsequent χ_r^2 value of the model profile and data block. If this cloud top was less than the ceiling, the block was not modeled as a low cloud and fog case. Low cloud and fog cases gave the results in figures 16 through 27.

Figure 16 shows the frequency distribution of the measured extinction at 2 m in steps of 2 km^{-1} for the 293 low cloud and fog data blocks. The most likely surface extinction is 14 km^{-1}, although it can range from 2 to 24 km^{-1}. Most of these data blocks represent fogs with an extinction at 2 m greater than 7 km^{-1} and a z_c of 0 m.

Figure 16. Frequency distribution of the surface extinction in steps of 2 km^{-1} for the low cloud/fog cases.

Figure 17 is the frequency distribution in steps of 10 m of the cloud thickness that minimizes χ_r^2. For these data blocks, the most common thickness is only 80 m; many blocks (~50) evidence a cloud less than 30-m thick. The previous XSCALE default was 200 m. The default has been changed to 100 m. This frequency distribution highlights the danger of using the model default value for all runs.

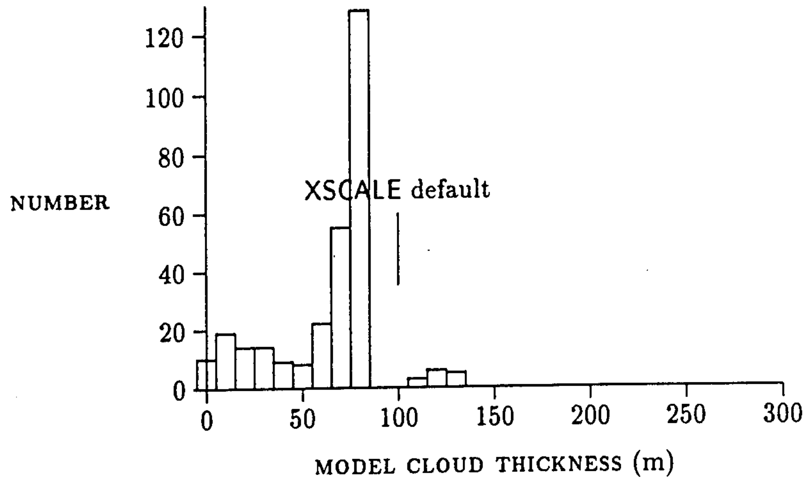


Figure 17. Frequency distribution of the cloud thickness which minimizes χ_r^2 in steps of 10 m for low cloud/fog cases.

Figure 18 shows the frequency distribution of the extinction at 300 m in steps of 0.025 km^{-1}. Since XSCALE employs clear air extinction above clouds, the model default is 0.030 km^{-1}. The most common extinction is 0.075 km^{-1}; this is the limit of the visibility meters used for the measurements. A very broad range of greater extinctions were measured at a significant frequency of occurrence, suggesting that clear air is not always immediately above fogs or cloud tops.

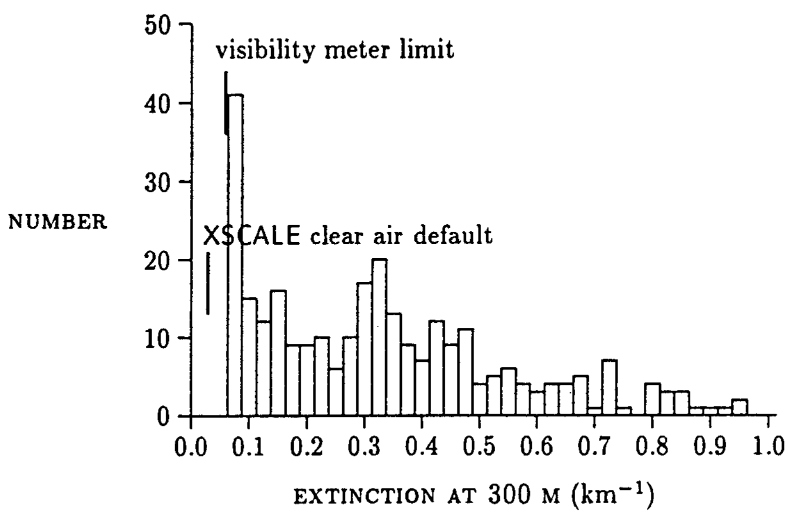


Figure 18. Frequency distribution of the upper air extinction in steps of 0.025 km^{-1}.

For many applications, the most important question is whether XSCALE calculates a reasonable transmittance. Figure 19 shows the path transmittance (from 2 to 300 m) calculated from the measured visibilities compared to the path transmittance determined by the XSCALE extinction profile at the tower stations. In almost every case, the transmittance agrees within the measurement uncertainty; this is shown by the error bars overlapping the slope 1 line. The most frequent transmittance is about 10 percent.

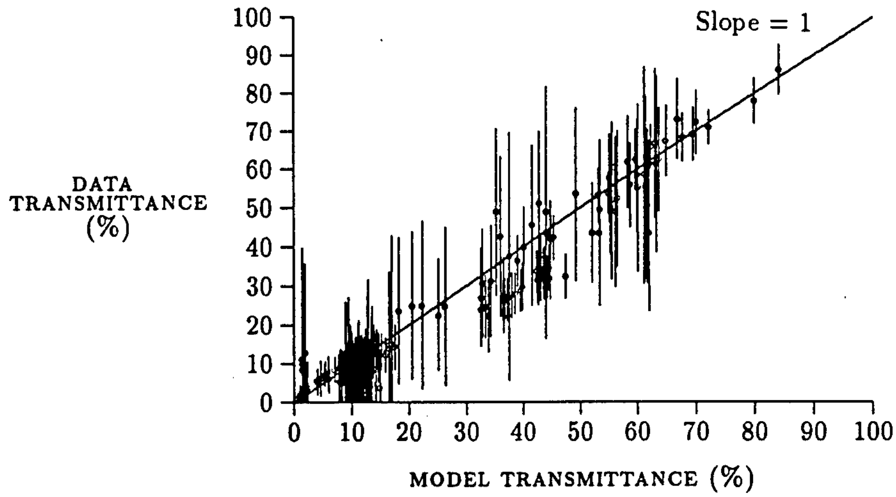


Figure 19. Transmittance determined from the measured visibilities (y-axis) versus transmittance calculated from the model extinction (x-axis) for the low cloud/fog cases. The line has slope 1.

Two representative data blocks are shown in figures 20 and 21. Figure 20 demonstrates good agreement ($\chi_r^2 = 1.0$); figure 21 demonstrates marginal agreement ($\chi_r^2 = 2.0$). Both figures illustrate a difficulty in the data samples. The calculation of z_C and the selection of z_T places a thin cloud between two of the observation levels. Since both the data and model transmittance are calculated from extinction at the six tower platforms, they agree with each other. However, had XSCALE been run for these parameters along a continuous path, a much lower transmittance would have been found. The few measurement altitudes in each data block severely restrict any conclusions that may be drawn from this data.

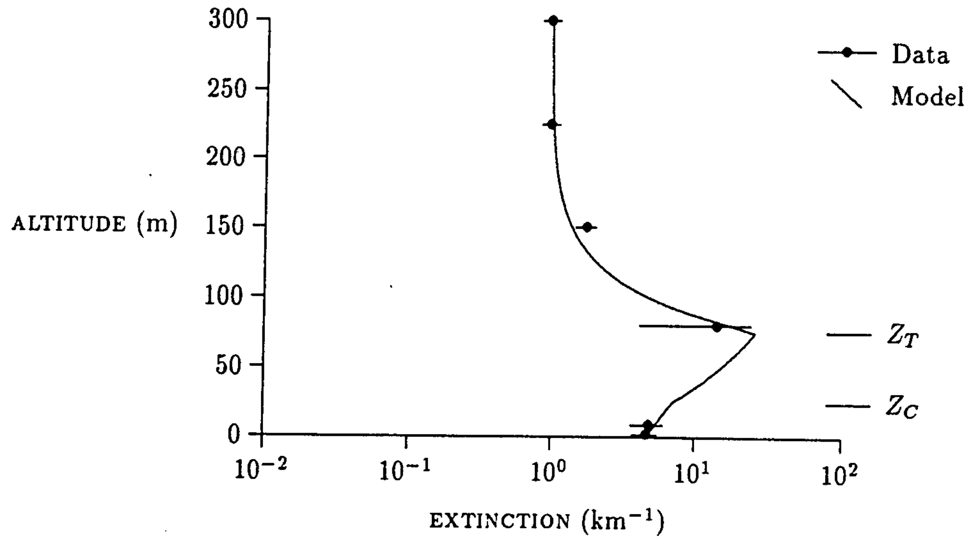


Figure 20. Low cloud profile, $\chi_r^2 = 1.0$, transmittance calculated from the data is 23 ±19 percent, from the model 18 percent. The measured ceiling is 35 ±8 m, the calculated ceiling is 25 m, the cloud top is at 76 m.

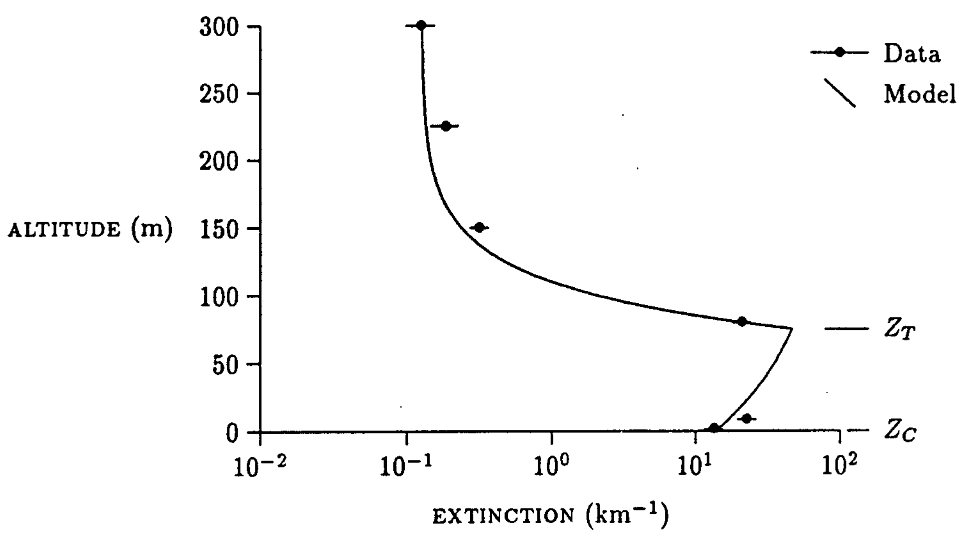


Figure 21. Advection fog profile, $\chi_r^2 = 2.0$, transmittance calculated from the data is 8 ±3 percent, from the model 11 percent. The measured ceiling is 10 ±8 m, the calculated ceiling is 0 m, the cloud top is at 75 m.

Inversion layer cases gave the following results. Figure 22 is the frequency distribution of the 2-m extinction measurement in steps of 1 km^{-1} for the 119 data blocks representative of the inversion layer case. Two separate values, 5 km^{-1} and 23 km^{-1}, of the surface extinction are very common. Surface extinctions above 7 km^{-1} are identified as fogs in this XSCALE user's manual. Lower extinctions are haze inversion layers. The blocks are nearly equally split between fogs and inversions. Figure 23 shows the frequency distribution of the 300-m extinction in 0.025-km^{-1} steps. The most common extinction is 0.075 km^{-1}, the upper limit of the visible meters. Again, higher extinction values were found, indicating other than clear air above this layer.

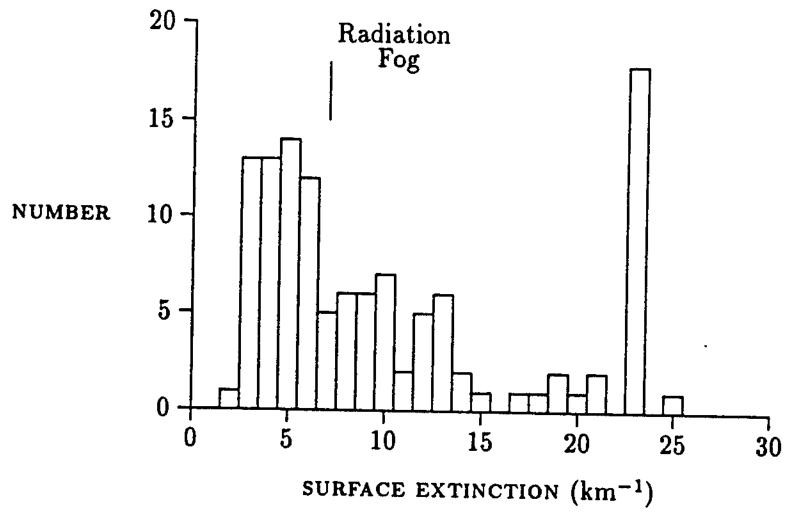


Figure 22. Frequency distribution of the surface extinction in steps of 1 km^{-1} for inversion layer cases.

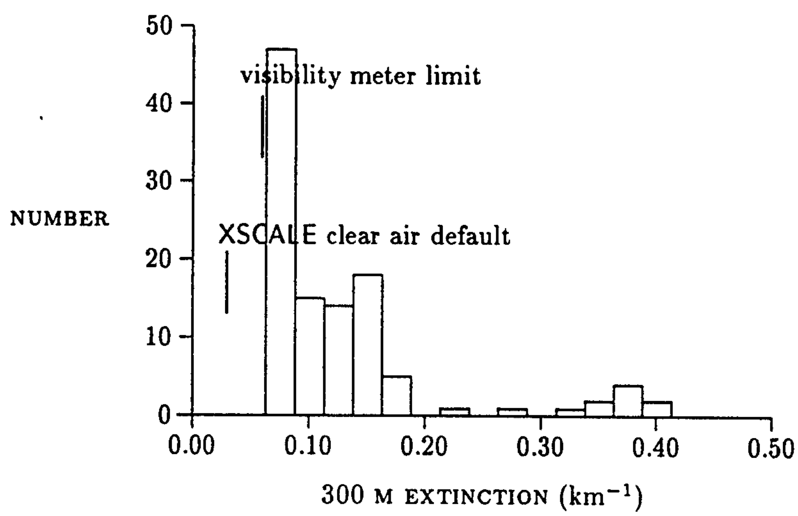


Figure 23. Frequency distribution of the upper air extinction in steps of 0.025 km^{-1} for inversion layer cases.

Figure 24 is the frequency distribution in 10-m steps of the modeled inversion height. The most likely height is approximately 170 m, although other heights are quite common. The XSCALE default height was 200 m, underestimating transmittance by approximately 15 percent. Thin layers, of heights less than 100 m, are also common. The XSCALE default has been changed to 100 m. However, no default should always be used. The subroutine VSA, which is the LOWTRAN 7 [7] implementation of XSCALE, sets a default of 50 m if the surface visibility is less than 2.0 km (extinction greater than 1.5 km^{-1}); this is true for all these data blocks. For most of these blocks, this would drastically underestimate the transmittance.

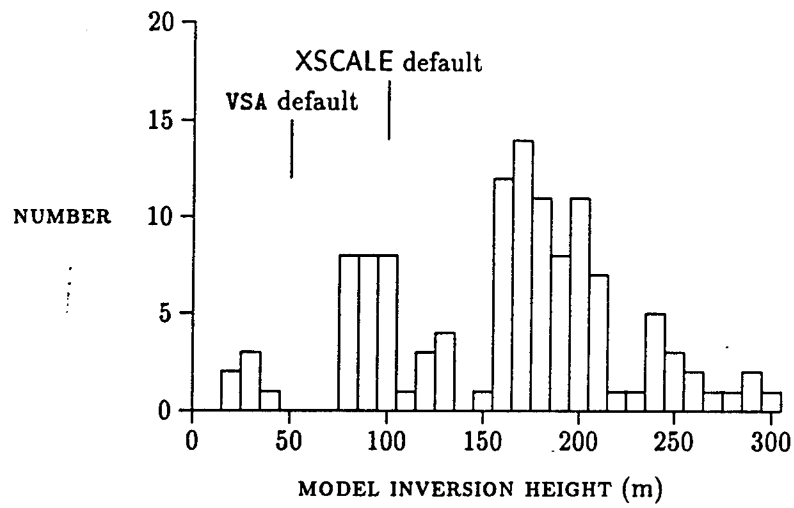


Figure 24. Frequency distribution of the inversion layer height determined to minimize χ_r^2 in steps of 10 m.

Figure 25 compares the transmittance calculated from the measured visibilities with that calculated from the XSCALE profile. Most of the points lay along the slope 1 line; many points show that XSCALE overestimates the transmittance.

Figure 26 shows a representative data block of low χ_r^2 (0.5). Figure 27 is typical of high χ_r^2 (2.0). The inversion height used in figure 26 appears to fit the data well. The height calculated from the temperature profile is 188 ±38 m; this is clearly inappropriate for these extinction values. The inversion height used for the data graphed in figure 27 is 122 m. The temperature profile suggests 115 ±35 m for this block, showing good agreement.

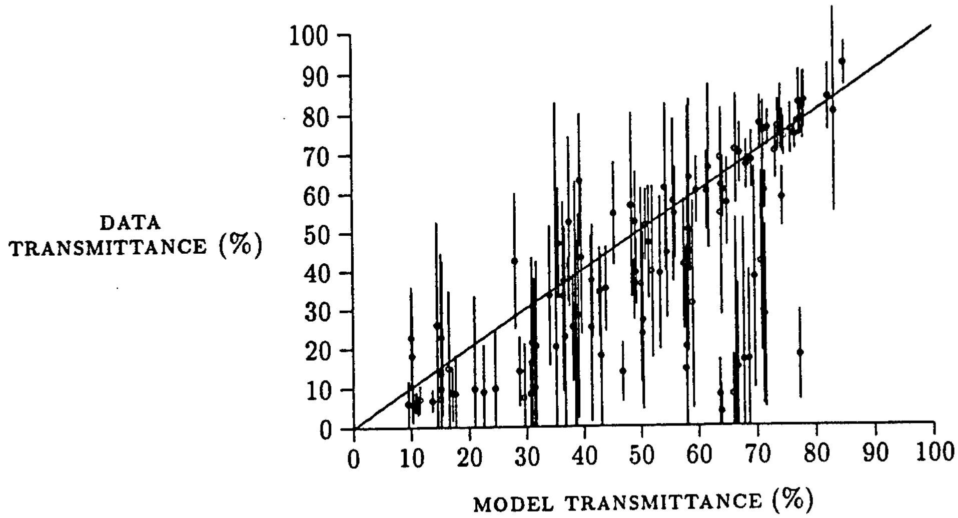


Figure 25. Transmittance determined from the measured visibilities (y-axis) versus transmittance calculated from the model extinctions (x-axis) for the inversion layer cases. The line has slope 1.

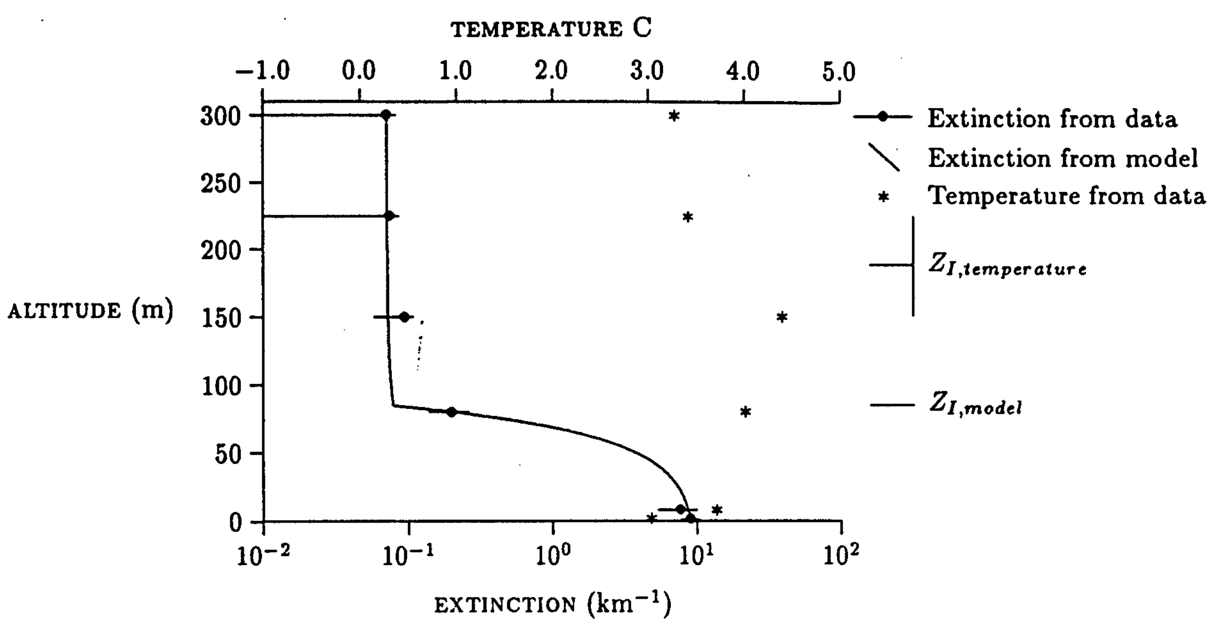


Figure 26. Inversion profile, $\chi_r^2 = 0.5$; transmittance calculated from the data is 70 ±8 percent, from the model 67 percent.

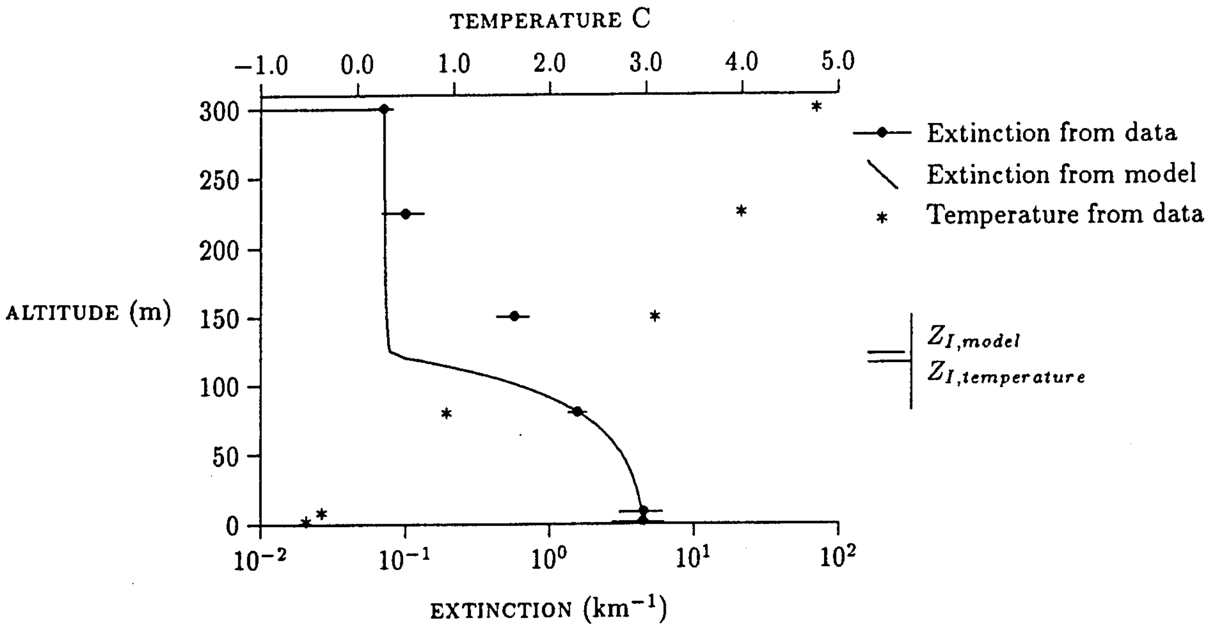


Figure 27. Inversion profile, $\chi_r^2 = 2.0$; transmittance calculated from the data is 70 ±7 percent, from the model 73 percent.

3.3.2.3 *Vertical profile model and the Meppen, Cardington, and Sprakensehl visible extinction.*— Comparisons were made of data from three separate measurement programs to the XSCALE vertical profile model visible extinction predictions. [50] All the extinction profiles and any associated data from one such measurement program are termed a data set. The data making up a single measured extinction profile are termed a data block, or a measured profile. The earliest set is from the Meppen 1980 measurement program. [4] A tethered balloon carried particle counters between the surface and approximately 750 m. The flights occurred during November and December (figure 28).

The Cardington set is from tethered balloon flights near Cardington, England, in January and February 1983. [5] Figure 29 shows the times at which the measurements were taken. The flights went to approximately 1300 m.

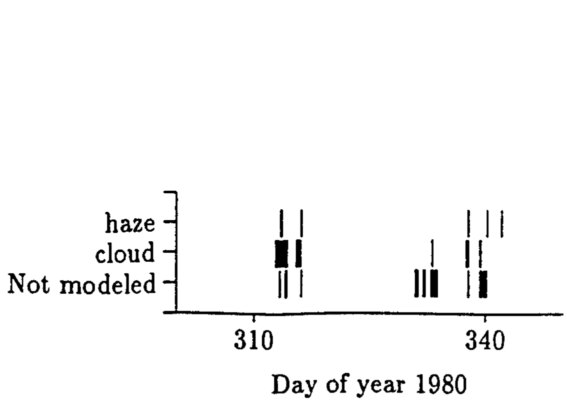


Figure 28. Meppen balloon flight data times. The y-axis denotes the type of profile, or an unsuitable data block.

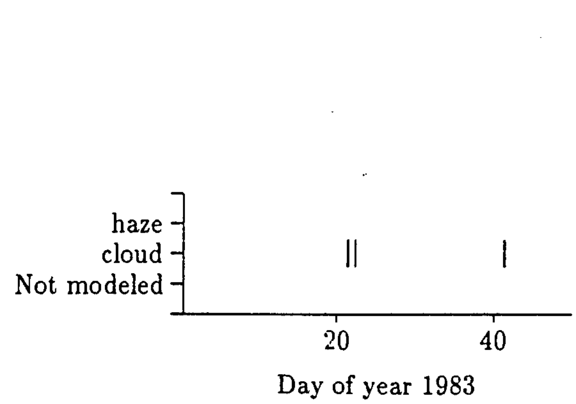


Figure 29. Cardington balloon flight data times. The y-axis denotes the type of profile, or an unsuitable data block.

The Sprakensehl measurements cover the greatest period (1983 – 1985). [50] These measurements are from visibility meters mounted at six stations of a radio mast at heights of 2, 9, 80, 150, 225, and 300 m. Low visibility occurrences of type III.A.1 are examined here; these are episodes when at least the 300-m station was above the low visibility layer. These occurrences of ground fog, very low clouds, or haze and inversion layers. Most of these episodes occurred in late fall and winter, although some were during spring and summer. Figure 30 gives the measurement times of the data blocks and whether a particular data block was cloud-like, haze-like, or not modeled.

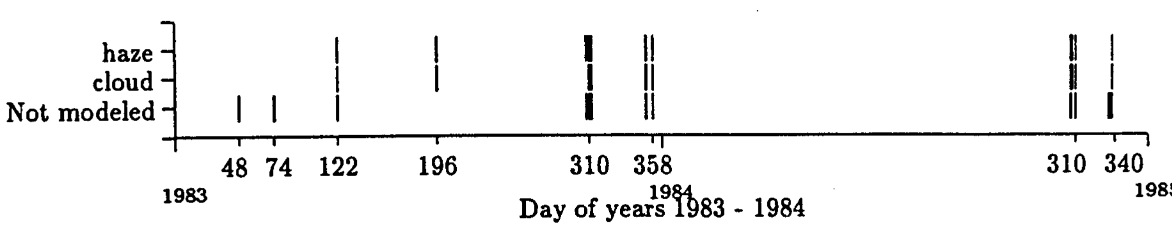


Figure 30. Sprekensehl tower data, type III.A.1 episode times. The y-axis denotes the type of profile, or an unsuitable data block.

Figure 31 shows the frequency distribution of the reduced chi-squared, χ_r^2, for the case 1 (fog and low cloud) data sets. The Meppen data result in values less than or near 10.0, while the Sprakensehl data show values of approximately 30. The reason for the large Sprakensehl

values can be traced to the visibility meters used. The upper limit of these meters is 50 km; the XSCALE profile above a cloud quickly approaches a value of 100 km. One or two points out of six with this much difference will easily result in a χ_r^2 value of 30. The Cardington set results in high χ_r^2 caused by multiple layers found in the large altitude range (~ 1300 m) covered.

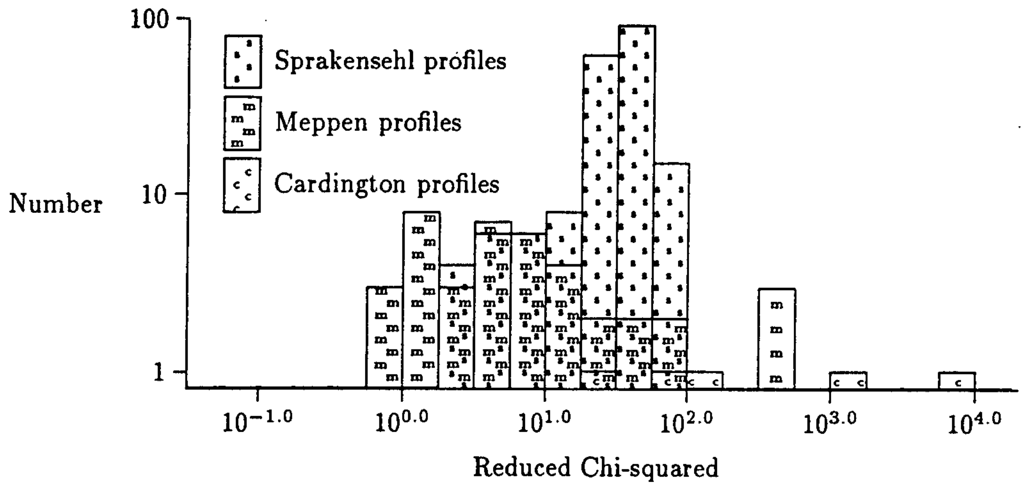


Figure 31. Frequency distribution of χ_r^2 between measured and XSCALE cloud profiles.

Figure 32 shows a similar frequency distribution for case 2 (haze layer) data sets. Here the Meppen data also show large χ_r^2. Above a haze layer, the particle counters frequently obtained a particle size distribution reflecting clearer air, but not as clear as that measured above clouds.

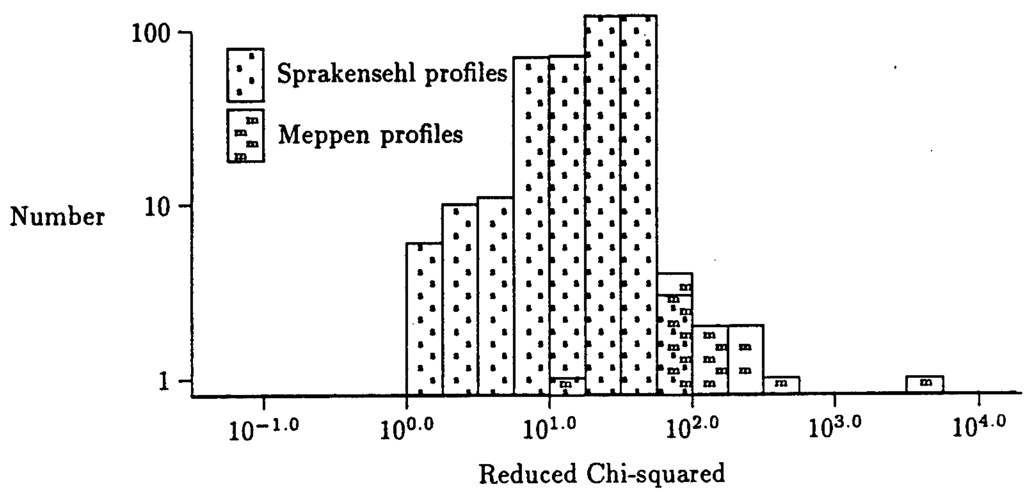


Figure 32. Frequency distribution of χ_r^2 between measured and XSCALE haze profiles.

Figures 33 through 42 show representative data sets and XSCALE calculated profiles that contributed to the above χ_r^2 frequency distributions. Data sets reflecting both low and high χ_r^2 values are shown from the Meppen, Cardington, and Sprakensehl measurement programs. Figures 33 through 38 display case 1 occurrences; figures 39 through 42 show case 2 samples. While at any particular altitude, the agreement between the measured and the XSCALE profile may be poor, the overall agreement is good. This is reflected by the transmissions and is noted on the graphs by T_{data} and T_{xscale} for transmission directly calculated from the data and from the XSCALE profile for each data block. Even the very high χ_r^2 of figure 33 appears to be a reasonable fit. This large χ_r^2 value arises from: (1) low uncertainty in the points; (2) a cloud profile not quite identical with that of XSCALE; and (3) above cloud extinction greater than that of the clear air profile.

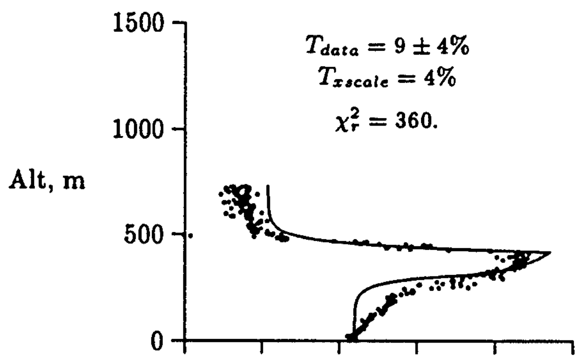


Figure 33. Meppen flight 1 and XSCALE profile.

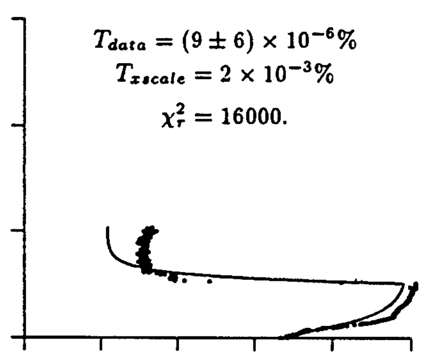


Figure 34. Meppen flight 7 and XSCALE profile.

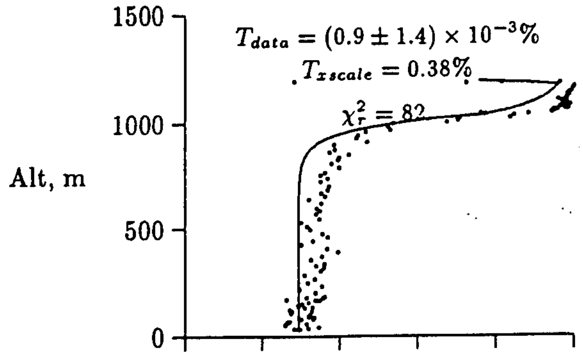


Figure 35. Cardington flight 5 and XSCALE profile.

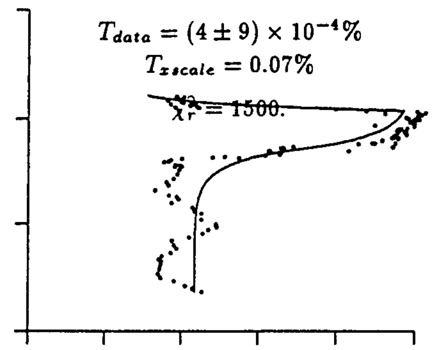


Figure 36. Cardington flight 27 and XSCALE profile.

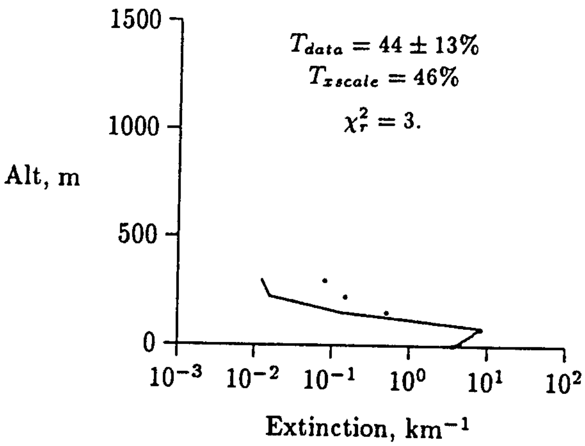


Figure 37. Sprekensehl block 14 and XSCALE profile.

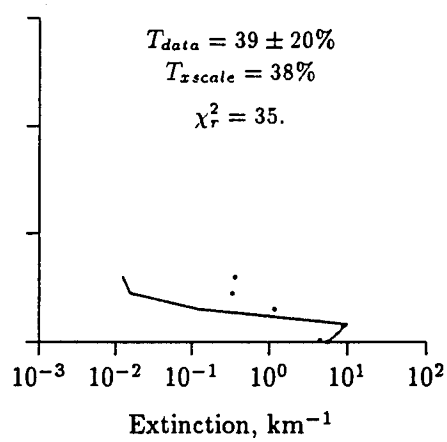


Figure 38. Sprekensehl block 926 and XSCALE profile.

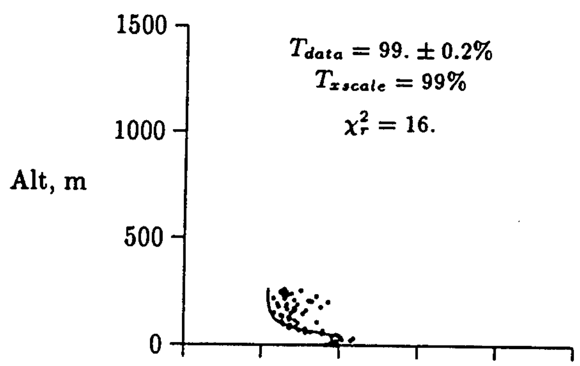


Figure 39. Meppen flight 89 and XSCALE profile.

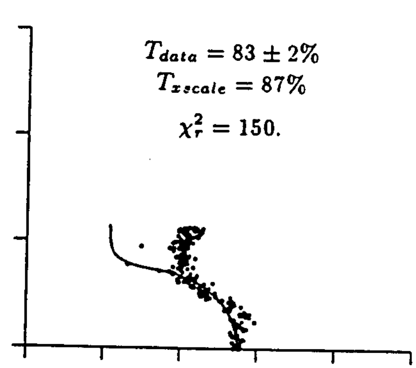
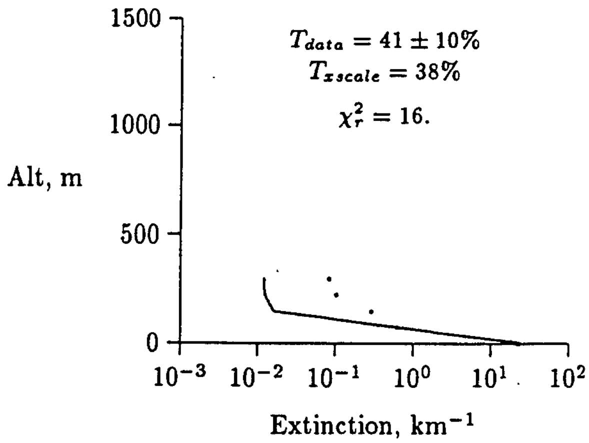


Figure 40. Meppen flight 53 and XSCALE profile.



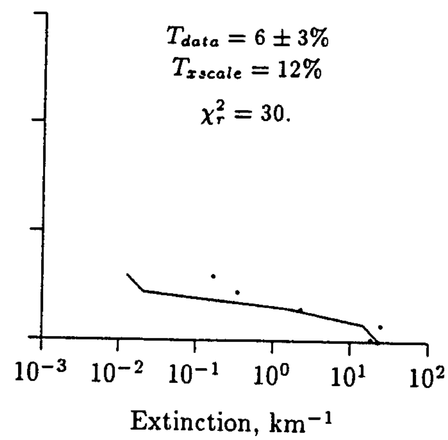


Figure 41. Sprekensehl block 735 and XSCALE profile.

Figure 42. Sprekensehl block 790 and XSCALE profile.

All five available profiles measured at Cardington were cloud layers with a ceiling more than 1000 m. The visible extinction profiles agreed with those predicted by XSCALE. Project Meppen 80 produced 89 profiles, 40 of which were those of stratus clouds and 11 of which were haze layer under clear air. These were well modeled by XSCALE. The remaining 38 profiles were incomplete, showed no structure, or demonstrated problems with the instruments; these were not considered. Of 733 episodes at the Sprakensehl tower: (1) 263 were episodes of clear air over radiation fog or haze concentrated in an inversion layer; (2) 152 were low cloud episodes; (3) 127 had missing data and were not considered; and (4) 191 were profiles not represented by XSCALE. These numbers are different from the earlier Sprakensehl study since that study adjusted the clear air extinction value to minimize χ_r^2 and determine the profile type. The earlier study stated that $\chi_r^2 \leq 2.0$ in order to determine a profile type. The predictions critically depend on surface visibility, cloud ceiling height, and cloud thickness. Approximately one-fourth of the Sprakensehl profiles exhibited structure that is not modeled by XSCALE. These structures appear to be multiple layers, such as a ground haze under clear air under a cloud, or a low cloud under a haze layer under clear air. The Sprakensehl data are not spatially dense enough to be certain of this.

4. Operations Guide

4.1 Inputs

Section 4.1.1 describes the records that XSCALE recognizes and reads for input. XSCALE can read ten different input records. These are: AERO, HORZ, SLNH, SLNS, CLD, ICEF, PLOT, RESF, GO, and DONE. The inputs associated with these records will be described first, then the interrelationships of the input (i.e., which inputs are really needed for various scenarios). Records specific to the EOSAEL driver program are not described. These EOSAEL records are included in the input files covered in section 4.1.2 for completeness.

4.1.1 Input Records

An image of each input record is given in its own table. A default is a value assigned to a Fortran variable if the variable does not contain an acceptable value. A blank field will be read as zero; this will be assigned to the corresponding variable. The first two lines of the table identify the column numbers; these are present to aid in field identification, but should not be in the input file. The following line begins with the record identifier, then the Fortran variables that are assigned the values appearing on the record. The remainder of the table describes each variable and expected value in turn. All values on the records are to be real numbers; these are converted to integers when assigned to integer variables.

Table 8. The AERO record. Use this record to specify the aerosol present, the required meteorological parameters, and one detector parameter

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
AERO           IAERO      RNRT       RH         TEMP      WNDVEL          RD
```

NAME	UNITS	Description
IAERO	Index	Aerosol index. XSCALE predicts the transmission through this aerosol. The choices are shown below. When choosing the air mass 1, 2, or 3 consideration should be given to where the air came from, rather than the local geographical position. For instance, to predict the transmission across a farmer's field one may at first thought select a rural air mass. However, if the field is within 100 miles of a sea coast and the prevailing wind has been from the coast, the maritime air mass may be appropriate. If the field is outside an urban area and the wind is from the city, then the urban air mass may be appropriate. The fog, rain, snow, and icefog conditions are described in Chapter 2. Aerosol index — Description 1.0 — Maritime air mass (arctic and polar) 2.0 — Urban air mass 3.0 — Rural air mass (continental polar) 4.0 — Fog one (heavy advection) 5.0 — Fog two (moderate radiation) 6.0 — Desert air mass 7.0 — Rain (drizzle) 8.0 — Rain (widespread) 9.0 — Rain (thunderstorm) 10.0 — Snow (Falling or blowing. Includes fog if relative humidity is above 95%) 11.0 — Icefog The default is 1, the maritime aerosol.
RNRT	mm/hr	The rain rate. Required for rain aerosols only, IAERO $\in \{7,8,9\}$. The default is 3 mm/hr.
RH	percent	The surface value of the relative humidity. This is required for air mass hazes and snow, IAERO $\in \{1,2,3,10\}$. The default is 70 % unless the climatology option has been specified through an EOSAEL record.
TEMP	degrees C	The surface value of the temperature. This is required for snow and icefog, IAERO $\in \{10,11\}$. The default is 0 C unless the climatology option has been specified through an EOSAEL record.
WNDVEL	m/sec	The surface value of the wind speed. This is required for snow, IAERO $\in \{6,10\}$. The default is 2 m/sec unless the climatology option has been specified through an EOSAEL record.
RD	cm	The detector radius, needed for snow transmittance. This is required for snow, IAERO $\in \{10\}$. The default is 10 cm.

Table 9. The HORZ record. Use this record for a horizontal path

```
           1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
HORZ           HORDI     ALT
```

NAME	UNITS	Description
HORDI	km	Horizontal distance or range over which the transmission is to be predicted. The default path is a 1.0 km horizontal path.
ALT	km	Altitude of transmission path above the surface. The default is 0.0 km, the surface.

Table 10. The SLNH record. Use this record for slant path predictions. One of two ways to specify a slant path

```
           1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SLNH           HORDI     ANG       ALT
```

NAME	UNITS	Description
HORDI	km	Horizontal distance over which the transmission is to be predicted. The default is 1.0 km.
ANG	degrees above horizon	The elevation angle. The default is 0.0 degrees, a horizontal path.
ALT	km	Altitude of one endpoint of transmission path. If ANG is greater than 0, then the path is considered to be looking upward and ALT is the lower endpoint. If ANG is less than 0, then the path is considered to be looking downward and ALT is the higher endpoint. The default is 0.0 km for the lower endpoint, the surface.

Table 11. The SLNS record. Use this record for slant path predictions. One of two ways to specify a slant path

```
           1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SLNS           SLNDI     ANG       ALT
```

NAME	UNITS	Description
SLNDI	km	Slant distance or range over which the transmission is to be predicted. The default is 1.0 km.
ANG	degrees above horizon	The elevation angle. The default is 0.0 degrees, a horizontal path.
ALT	km	Altitude of one endpoint of transmission path. If ANG is greater than 0, then the path is considered to be looking upward and ALT is the lower endpoint. If ANG is less than 0, then the path is considered to be looking downward and ALT is the higher endpoint. The default is 0.0 km for the lower endpoint, the surface.

Table 12. The CLD record. Use this record to specify the altitude of the low visibility layer

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CLD           CEILHT     THICK     AINVHT
```

NAME	UNITS	Description
CEILHT	km	Cloud ceiling height (base of cloud) above ground. This must be given as a value greater than or equal to zero if the XSCALE prediction is to include the effect of a cloud. The value should be negative if a cloud is not to be modeled. The default is -1.0, no cloud present.
THICK	km	Cloud thickness. The default is 0.0. Unless CEILHT is greater or equal to 0.0 or fog-one has been specified (IAERO = 4), then 0.100.
AINVHT	km	Inversion layer thickness. This must be given as a value greater than zero if an inversion layer is to be modeled. The inversion is taken to begin at ground level and continue upward to this height. The value should be negative if an inversion layer is not to be modeled. The default is -1.0, no inversion present. Unless fog-two has been specified (IAERO = 5), then 0.100.

Table 13. The ICEF record. Use this record to provide nondefault information for the ice fog aerosol. One to three ICEF records may be present, one for each water vapor source (see section 2.1.7 and table 4)

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
ICEF          ISOURC    DECPER    XMEAN     XMODE     IWATER
```

NAME	UNITS	Description
ISOURC	Index	An index identifying the source of water vapor causing the icefog. ISOURC value — Description 0.0 — Accept the algorithm defaults depending on nearness to open water 1.0 — Vehicle exhaust 2.0 — Heating plant flues 3.0 — Open water The default is 0.0
DECPER	0. – 1.	Fraction of particles of the source type ISOURC. The DECPER values on this and other ICEF records must add to 1.0. The default is 0.
XMEAN	μm	Mean diameter of the source particles. This is optional, although either this or XMODE must be specified if ISOURC $\neq$ 0. The default is 0.
XMODE	μm	Mode diameter of the source particles. This is optional, although either this or XMEAN must be specified if ISOURC $\neq$ 0.0 The default is 0.0
IWATER	Index	Descriptor of source nearness to open water. This is used if ISOURC = 0. IWATER value — Description 0.0 — Open water not nearby (default) 1.0 — Open water nearby The default is 0.

Table 14. The PLOT record. Use this record to direct the saving of the extinction profile generated by a slant path prediction

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
PLOT           NPLT
```

NAME	UNITS	Description
NPLT	Index	Index to direct the saving of a vertical profile to a file. See below. This file will contain profiles of relative humidity, visible extinction, and IR extinction, and the IR path average extinction at each altitude step for the wavelengths of interest. The first record (line) of the written file will contain the number of points and wavelength. (In 18X,I5,22X,F8.3 format) The second line holds column headings, and the subsequent records will contain aerosol type, altitude, relative humidity, visible extinction, IR extinction, and IR path average extinction up to the altitude. (In 2X,I2,2X,F5.0,2X,F6.2,3(1X,1PE10.4) format). Plotting index, NPLT — Description 0.0 — Do not save the profile 1.0 — Save to the default file, PROFIL 2.0 — Save to specified file If choice '2.0' is made the following unnamed record must contain a file name up to 12 characters long. The default is 0.

Table 15. The RESF record. Use this record to define a detector response function. The predicted aerosol transmittance will be modified by this function before the transmittance is printed out

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
RESF           NBR
```

NAME	UNITS	Description
NBR	Count	The number of wavelength dependent sensor response function values on following records. The maximum is 20.0. The following unnamed records must contain these values as wavelength (μm), response value ($0. - 1.$) pairs in (10X,2E10.4) format. These records should be in order of increasing wavelength. The device response is taken to be 0.0 outside this specified wavelength range, and linearly interpolated between the specified values. The default is 0., although use of this record implies the response at a single wavelength at least would be expected.

Table 16. The GO record. Use this record to specify that multiple XSCALE runs are to be made

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
GO
```

NAME	UNITS	Description
		The GO record signifies that input for the current run is complete and execution is to begin, another data set is expected to follow. Only records containing values that change need to be present in the next set of records for the next run. All values on a record will be renewed, either with the value on the record or with a default value. Previous values associated with a record are over-written.

Table 17. The DONE record specifies that input for the last (or only) XSCALE run is complete and execution is to begin

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
DONE
```

NAME	UNITS	Description
		Program control is returned to EOEXEC after this run is complete.

4.1.2 *Record Combinations*

A sample of possible input record combinations will now be given. The simplest input file contains only the records required by EOEXEC, and DONE is the sole required XSCALE record. All the XSCALE defaults are employed. This gives the prediction for a 1-km horizontal path through the maritime aerosol at the surface.

```
WAVL      3.0      5.0

VIS       10.0

XSCALE

DONE

END

STOP
```

More interesting and varied situations can be considered. There is one major choice to be made: whether the transmittance along a horizontal or slant path geometry will be predicted. For a horizontal path, the input records are:

```
WAVL      3.0      5.0

VIS       10.0

XSCALE

<AERO>

HORZ           5.0

<RESF>

 < >

 . . .

 < >

<ICEF>

<ICEF>

<ICEF>
```

```
<GO  >
 . . .
 DONE
 END
 STOP
```

Records enclosed in < > are optional. As shown, only two records are required: the HORZ record for the transmission path range (here 5.0 km; note that the path is at the surface since no value for ALT is present and the default is 0.0 km), and the DONE record. No AERO record results when maritime aerosol at 70 percent humidity is used. If RESF is used, the sensor response curve must follow. If GO is used, at least one more input set must follow. One to three ICEF records may be present if the aerosol index corresponding to ice fog is present on the AERO record. The PLOT and CLD records are not used since the vertical structure is not calculated.

For a slant path, the input records are as follows:

```
<AERO>
[SLNH, SLNS]    5.0
<CLD >
<PLOT>
<    >
<RESF>
  < >
 . . .
  < >
<GO  >
 . . .
 DONE
```

Again, only two records are required: '[ ]' indicates that one of the enclosed must be used. If the CLD record is not used, a clear air condition will be the default (The values of CEILHT, THICK, and AINVHT will be initialized as -1.0, 0.0, and -1.0). If PLOT is present, the following record may contain a user specified file name; this is allowed for by the NPLT value contained on the PLOT record. The ICEF record is not present because XSCALE will not calculate a vertical profile for the rain, snow, or ice fog aerosols.

All the input values contained on the AERO record are not needed for all the aerosol choices. Table 8 attempts to clarify the inputs that are needed for each aerosol. If a value is not required, the field may be left blank; this is true for any XSCALE input record.

4.2 Output

All output is 80 columns wide or less. The chosen input parameters are written to output. Undefined values will have been assigned a default value; these are identified by "DEFAULT" labels. The output calculations are the extinction, scattering, and absorption coefficients averaged over the path and the wavelength band. The path and wavelength averaged transmittance is also printed. The particular outputs are discussed in the next chapter.

5. Sample Runs

5.1 Overview

Two simple examples will be given in sections 5.2 and 5.3. The simplest horizontal and slant path cases are demonstrated, employing defaults wherever possible. This is the minimum amount of inputs required to make XSCALE run.

Section 5.4 will show a multiple run (use of GO) for a single horizontal path and wavelength region requesting predictions for each aerosol in turn. Section 5.5 will contain a single run for a slant path into a cloud; the profile will be saved to a file.

Section 5.6 will present a file for multiple runs through fog, rain, and maritime aerosols. The path is the same for each; the transmittance of the 3 – 5 µm band is very dependent on the aerosol. In section 5.7, two files show the influence a single input value can have on the prediction made and therefore, the necessity to read the output labels. Section 5.8 has a final file that demonstrates the use of the RESF record for the 8 – 12 µm band.

5.2 Default Horizontal Path

The input file for a simple horizontal case follows. The 3 – 5 µm wavelength band is requested, the surface visibility is 10.0 km, and the XSCALE module is specified. These three lines are required by the EOSAEL driver program. The next line is the minimum XSCALE record, the DONE record. The AERO record need not be present; the defaults will be accepted. The transmission over a 1-km path will be calculated (if the HORZ record is not present) The run ends, the next two lines are required by EOSAEL. The final two lines of the input file are used to help the reader place values in the proper columns. They are not read.

```
WAVL      3.0       5.0

VIS       10.0

XSCALE

DONE

END

STOP
12345678901234567890123456789012345678901234567890123456789012345678901234567890
0        1         2         3         4         5         6         7         8
```

The output from this run is as follows:

```
*****************************************************************************

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  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO

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                    * EOSAEL87 REV 2.1   02/23/90  *
                    *                              *
                    ********************************

WAVL       3.0        5.0

 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:

WAVL        .3000E+01 .5000E+01 .0000E+00

                                          BEGINNING           ENDING

             WAVENUMBER (CM**-1)          2000.000            3333.333

             WAVELENGTH (MICROMETERS)        3.000               5.000

             FREQUENCY (GHZ)             60000.000          100000.000

                                     VISIBILITY

                                      10.00 KM

1

                    ********************************
                    *                              *
```

```
*        X S C A L E          *
*                             *
*       NATURAL AEROSOL       *
*         EXTINCTION          *
*           MODULE            *
*                             *
* EOSAEL87  REV 00  27 OCT 87 *
*                             *
*******************************
```

XSCALE RUN # 1

OPTIONS CHOSEN: AEROSOL MODEL WAS NOT RECOGNIZED

MARITIME AEROSOL MODEL [BY DEFAULT]

RELATIVE HUMIDITY 70.00 PERCENT (DEFAULT VALUE)

SURFACE RELATIVE HUMIDITY IS GREATER THAN 99%,

ADVECTION FOG WILL BE SUBSTITUTED FOR CHOSEN AEROSOL

HORIZONTAL PATH (DEFAULT VALUE)

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	ABSORPTION	SCATTERING	DISTANCE	TRANSMISSION
1/KM	1/KM	1/KM	KM	%
1.4566E-01	1.9413E-02	1.2625E-01	1.000	8.6445E+01
			(DEFAULT VALUE)	

TOTAL TRANSMITTANCE FOR ALL SOURCES IS: .8645E+00

END EOSAEL RUN

STOP 000

5.3 Simplest Slant Path

The next run models a slant path. The only difference is that the `SLNS` record is used. This specifies a 10-km range (total path length) and a 30° elevation angle.

```
WAVL     3.0      5.0
VIS      10.0
XSCALE
SLNS     10.0     30.0
DONE
END
STOP
C234567890123456789012345678901234567890123456789012345678901234567890123456789O
C        1         2         3         4         5         6         7         8
```

The output from this file is:

```
*******************************************************************************

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                    *                              *
                    * EOSAEL87 REV 2.1   02/23/90  *
                    *                              *
                    ********************************
WAVL       3.0        5.0
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL        .3000E+01 .5000E+01 .0000E+00
                                          BEGINNING            ENDING
             WAVENUMBER (CM**-1)          2000.000             3333.333
             WAVELENGTH (MICROMETERS)        3.000                5.000
             FREQUENCY (GHZ)             60000.000           100000.000
                                     VISIBILITY
                                      10.00 KM
1
                    ********************************
                    *                              *
```

```
*         X S C A L E          *
*                              *
*       NATURAL AEROSOL        *
*         EXTINCTION           *
*           MODULE             *
*                              *
* EOSAEL87  REV 00   27 OCT 87 *
*                              *
********************************
```

XSCALE RUN # 1

OPTIONS CHOSEN: AEROSOL MODEL WAS NOT RECOGNIZED

MARITIME AEROSOL MODEL [BY DEFAULT]

RELATIVE HUMIDITY 70.00 PERCENT (DEFAULT VALUE)

SURFACE RELATIVE HUMIDITY IS GREATER THAN 99%,

ADVECTION FOG WILL BE SUBSTITUTED FOR CHOSEN AEROSOL

SLANT PATH

WIDEBAND WAVELENGTH AVERAGE

THERE IS NO INVERSION OR CLOUD LAYER PRESENT

SLANT DISTANCE KM	VERTICAL DISTANCE KM	HORIZONTAL DISTANCE KM	ANGLE DEGREES
10.000	5.000	8.660	30.00

XSCALE ONLY PREDICTS FOR 0 - 2 KM BOUNDARY LAYER

SLANT, VERTICAL, AND HORIZONTAL DISTANCES REDUCED

4.000	2.000	3.464

PATH IS ABOVE THE SURFACE, ALTITUDE RANGES

FROM .001 TO 5.001 KILOMETERS

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION 1/KM	DISTANCE KM	TRANSMISSION %

```
                    1.6967E-02        10.000        8.4394E+01

                TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .8439E+00

                               END EOSAEL RUN

STOP 000
```

5.4 Multiple Runs, Horizontal Path

The transmittance for each aerosol (in order) will be calculated for a 10-km horizontal path. The visibility is 1 km, and a wideband average will again be requested. The default relative humidity is employed for the maritime, urban, rural, advection fog, and radiation fog aerosols. Rain rates of 1.0, 3.0, and 6.0 mm/h are specified for drizzle, widespread, and thunderstorm rain aerosols. This is the only meteorological parameter required for rain. Three different snow conditions are specified. The default detector radius will be employed. First is falling snow, which has a 30 percent relative humidity, a temperature of -3 °C, and a wind speed of 3 m/s (a wind speed less than 5 m/s indicates falling snow). Second is blowing snow, which has a 30 percent relative humidity, a temperature of -3 °C, and a wind speed of 7 m/s (a wind speed of greater than 5 m/s indicates blowing snow). Finally, there is snow and fog, which has a 98 percent relative humidity, a temperature of 3 °C, and a wind speed of 3 m/s (a wind speed of less than 5 m/s indicates falling snow, while a relative humidity of greater than 95 percent indicates the presence of fog as well). The output is as follows:

```
WAVL      3.0       5.0

VIS       10.0

XSCALE

HORZ      10.0

AERO      1.0

GO

AERO      2.0

GO

AERO      3.0

GO
```

```
AERO    4.0
GO
AERO    5.0
GO
AERO    6.0       1.0
GO
AERO    7.0       3.0
GO
AERO    8.0       6.0
GO
AERO    9.0                 30.0      -3.0      3.0
GO
AERO    9.0                 30.0      -3.0      7.0
GO
AERO    9.0                 98.0      3.0       3.0
DONE
END
STOP
C2345678901234567890123456789012345678901234567890123456789012345678901234567890
C       1         2         3         4         5         6         7         8
```

```
******************************************************************************

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                     *                              *

                     * EOSAEL87 REV 2.1   02/23/90  *

                     *                              *

                     ********************************

WAVL      3.0       5.0

 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:

WAVL       .3000E+01 .5000E+01 .0000E+00

                                      BEGINNING          ENDING

             WAVENUMBER (CM**-1)      2000.000          3333.333

             WAVELENGTH (MICROMETERS)    3.000             5.000

             FREQUENCY (GHZ)         60000.000        100000.000

                                 VISIBILITY

                                  10.00 KM

1

                     ********************************

                     *                              *
```

```
*        X S C A L E        *
*                           *
*      NATURAL AEROSOL      *
*         EXTINCTION        *
*           MODULE          *
*                           *
* EOSAEL87  REV 00   27 OCT 87 *
*                           *
*******************************
              XSCALE RUN #   1
OPTIONS CHOSEN:   MARITIME AEROSOL MODEL
                  RELATIVE HUMIDITY  70.00 PERCENT  (DEFAULT VALUE)
                  HORIZONTAL PATH
                  WIDEBAND WAVELENGTH AVERAGE
         WIDEBAND AVERAGE: FROM   3.000 TO   5.000 UM
EXTINCTION  ABSORPTION  SCATTERING     DISTANCE     TRANSMISSION
   1/KM        1/KM        1/KM           KM              %
1.4566E-01  1.9413E-02  1.2625E-01     10.000        2.3303E+01
              XSCALE RUN #   2
OPTIONS CHOSEN:   URBAN AEROSOL MODEL
                  RELATIVE HUMIDITY  70.00 PERCENT  (DEFAULT VALUE)
                  HORIZONTAL PATH
                  WIDEBAND WAVELENGTH AVERAGE
         WIDEBAND AVERAGE: FROM   3.000 TO   5.000 UM
EXTINCTION  ABSORPTION  SCATTERING     DISTANCE     TRANSMISSION
   1/KM        1/KM        1/KM           KM              %
5.6911E-02  3.1176E-02  2.5735E-02     10.000        5.6603E+01
              XSCALE RUN #   3
OPTIONS CHOSEN:   RURAL AEROSOL MODEL
                  RELATIVE HUMIDITY  70.00 PERCENT  (DEFAULT VALUE)
```

HORIZONTAL PATH

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	ABSORPTION	SCATTERING	DISTANCE	TRANSMISSION
1/KM	1/KM	1/KM	KM	%
4.0803E-02	8.1393E-03	3.2664E-02	10.000	6.6496E+01

XSCALE RUN # 4

OPTIONS CHOSEN: FOG1 - HEAVY

RELATIVE HUMIDITY 100.00 PERCENT (DEFAULT VALUE)

HORIZONTAL PATH

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	ABSORPTION	SCATTERING	DISTANCE	TRANSMISSION
1/KM	1/KM	1/KM	KM	%
4.2276E-01	1.3774E-01	2.8502E-01	10.000	1.4587E+00

XSCALE RUN # 5

OPTIONS CHOSEN: FOG2 - LIGHT

RELATIVE HUMIDITY 100.00 PERCENT (DEFAULT VALUE)

HORIZONTAL PATH

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	ABSORPTION	SCATTERING	DISTANCE	TRANSMISSION
1/KM	1/KM	1/KM	KM	%
4.9355E-01	6.3155E-02	4.3039E-01	10.000	7.1871E-01

XSCALE RUN # 6

OPTIONS CHOSEN: DESERT AEROSOL

WIND SPEED 2.00 M/S (DEFAULT VALUE)

HORIZONTAL PATH

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	ABSORPTION	SCATTERING	DISTANCE	TRANSMISSION
1/KM	1/KM	1/KM	KM	%
5.4201E-02	1.2196E-02	4.2005E-02	10.000	5.8158E+01

XSCALE RUN # 7

OPTIONS CHOSEN: RAIN - DRIZZLE

RAIN RATE 3.00 MM/HR

HORIZONTAL PATH

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	DISTANCE	TRANSMISSION
1/KM	KM	%
1.0168E+00	10.000	3.8394E-03

XSCALE RUN # 8

OPTIONS CHOSEN: RAIN - WIDESPREAD MODEL

RAIN RATE 6.00 MM/HR

HORIZONTAL PATH

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	DISTANCE	TRANSMISSION
1/KM	KM	%
9.8974E-01	10.000	5.0306E-03

XSCALE RUN # 9

OPTIONS CHOSEN: RAIN - THUNDERSTORM

RELATIVE HUMIDITY 30.00 PERCENT

RAIN RATE 3.00 MM/HR (DEFAULT VALUE)

HORIZONTAL PATH

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	DISTANCE	TRANSMISSION
1/KM	KM	%

```
3.2667E-01        10.000        3.8134E+00

                  XSCALE RUN #  10

OPTIONS CHOSEN:   RAIN - THUNDERSTORM

                  RELATIVE HUMIDITY  30.00 PERCENT

                  RAIN RATE   3.00 MM/HR  (DEFAULT VALUE)

                  HORIZONTAL PATH

                  WIDEBAND WAVELENGTH AVERAGE

      WIDEBAND AVERAGE: FROM   3.000 TO   5.000 UM

      EXTINCTION      DISTANCE      TRANSMISSION

        1/KM             KM               %

      3.2667E-01        10.000        3.8134E+00

                  XSCALE RUN #  11

OPTIONS CHOSEN:   RAIN - THUNDERSTORM

                  RELATIVE HUMIDITY  98.00 PERCENT

                  RAIN RATE   3.00 MM/HR  (DEFAULT VALUE)

                  HORIZONTAL PATH

                  WIDEBAND WAVELENGTH AVERAGE

      WIDEBAND AVERAGE: FROM   3.000 TO   5.000 UM

      EXTINCTION      DISTANCE      TRANSMISSION

        1/KM             KM               %

      3.2667E-01        10.000        3.8134E+00

      TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .3813E-01

                  END EOSAEL RUN

STOP 000
```

5.5 Desert Aerosol, 3.392 μm

The following three files invoke the desert aerosol: First, the extinction at 3.392 μm, visibility of 68.51 km, and wind speed of 10 m/s^{-1} is requested. This should give the extinction, absorption, and scattering coefficients found in table C-2 of Longtin et al. [11] Next, the same wavelength and visibility are used, but the wind speed is increased to 15 m/s^{-1}.

The 3.392-μm wavelength is a He-Ne laser line. XSCALE can be used to calculated aerosol extinction at laser wavelengths since an aerosol air mass is a polydispersive ensemble of many different particles. Any wavelength dependence of a particular shape, size, or substance is washed out by the rest of the ensemble. The EOSAEL module LZTRAN should be used to calculate the gaseous extinction at a laser line. However, programs like LOWTRAN and MODTRAN should not be used for laser transmittance since the resolution is not great enough for the gaseous part.

```
WAVL     3.392

VIS      68.51

XSCALE

AERO     6.0                                     10.0

HORZ     1.0

GO

AERO     6.0                                     15.0

DONE

END

STOP

C2345678901234567890123456789012345678901234567890123456789012345678901234567890

C        1         2         3         4         5         6         7         8
```

```
*****************************************************************************
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                      *                              *
                      ********************************
WAVL      3.392
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .3392E+01 .3392E+01 .0000E+00
                                         BEGINNING          ENDING
            WAVENUMBER (CM**-1)          2948.113          2948.113
            WAVELENGTH (MICROMETERS)        3.392             3.392
            FREQUENCY (GHZ)             88443.398         88443.398
                                    VISIBILITY
                                     68.51 KM
 1
                      ********************************
                      *                              *
```

```
*          X S C A L E          *
*                               *
*       NATURAL AEROSOL         *
*          EXTINCTION           *
*            MODULE             *
*                               *
* EOSAEL87  REV 00   27 OCT 87 *
*                               *
*********************************
```

XSCALE RUN # 1

OPTIONS CHOSEN: DESERT AEROSOL

WIND SPEED 10.00 M/S

HORIZONTAL PATH

WAVELENGTH 3.392 MICROMETERS

SURFACE EXTINCTION = 2.3810E-02 1/KM

ABSORPTION = 3.3569E-03 1/KM

SCATTERING = 2.0453E-02 1/KM

SINGLE SCATTERING ALBEDO = .8590

EXTINCTION	DISTANCE	TRANSMISSION
1/KM	KM	%
2.3810E-02	1.000	9.7647E+01

XSCALE RUN # 2

OPTIONS CHOSEN: DESERT AEROSOL

WIND SPEED 15.00 M/S

HORIZONTAL PATH

WAVELENGTH 3.392 MICROMETERS

SURFACE EXTINCTION = 3.7201E-02 1/KM

ABSORPTION = 2.1324E-03 1/KM

SCATTERING = 3.5068E-02 1/KM

SINGLE SCATTERING ALBEDO = .9427

```
EXTINCTION                    DISTANCE           TRANSMISSION
   1/KM                          KM                   %
3.7201E-02                      1.000             9.6348E+01
         TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .9635E+00
                         END EOSAEL RUN
STOP 000
```

5.6 Desert Aerosol, 3.20 µm

The second file retains the visibility and initial wind speed but requests a calculation at 3.20 µm. These values will be found in table C-2 of Longtin et al. [11] but involve an interpolation within XSCALE.

```
WAVL     3.20
VIS      68.51
XSCALE
AERO     6.0                          10.0
HORZ     1.0
DONE
END
STOP
C2345678901234567890123456789012345678901234567890123456789012345678901234567890
C        1         2         3         4         5         6         7         8
```

```
*****************************************************************************
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                      *                              *
                      ********************************

WAVL      3.20
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .3200E+01 .3200E+01 .0000E+00
                                      BEGINNING           ENDING

              WAVENUMBER (CM**-1)      3125.000          3125.000

              WAVELENGTH (MICROMETERS)    3.200             3.200

              FREQUENCY (GHZ)         93750.000         93750.000

                                 VISIBILITY

                                  68.51 KM

1
                      ********************************
                      *                              *
```

```
*         X S C A L E          *

*                              *

*       NATURAL AEROSOL        *

*         EXTINCTION           *

*           MODULE             *

*                              *

* EOSAEL87  REV 00   27 OCT 87 *

*                              *

********************************

           XSCALE RUN #   1

OPTIONS CHOSEN:   DESERT AEROSOL

                  WIND SPEED  10.00 M/S

                  HORIZONTAL PATH

                  WAVELENGTH    3.200 MICROMETERS

        SURFACE EXTINCTION  =  2.3083E-02 1/KM

                ABSORPTION  =  2.9573E-03 1/KM

                SCATTERING  =  2.0126E-02 1/KM

  SINGLE SCATTERING ALBEDO  =   .8719

EXTINCTION               DISTANCE             TRANSMISSION

  1/KM                      KM                    %

2.3083E-02                 1.000               9.7718E+01

        TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .9772E+00

                   END EOSAEL RUN

STOP 000
```

5.7 Desert Aerosol, 3 – 5 μm

The third input file requests a 3 – 5 μm band average at 68.51-km visibility and a 10 m/s^{-1} wind speed. This should be an integration of values found in table C-2 of Longtin et al. [11] The output of these three files is as follows:

```
WAVL     3.00      5.00

VIS      68.51

XSCALE

AERO     6.0                                 10.0

HORZ     1.0

DONE

END

STOP

C2345678901234567890123456789012345678901234567890123456789012345678901234567890
C        1         2         3         4         5         6         7         8
```

```
********************************************************************************

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                    *                              *
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                    *                              *
                    * EOSAEL87 REV 2.1   02/23/90  *
                    *                              *
                    ********************************

WAVL     3.00     5.00

 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:

WAVL        .3000E+01 .5000E+01 .0000E+00

                                         BEGINNING          ENDING

              WAVENUMBER (CM**-1)         2000.000         3333.333

              WAVELENGTH (MICROMETERS)       3.000            5.000

              FREQUENCY (GHZ)            60000.000       100000.000

                                    VISIBILITY

                                     68.51 KM

1
                    ********************************
                    *                              *
```

```
                 *        X S C A L E          *

                 *                             *

                 *      NATURAL AEROSOL        *

                 *        EXTINCTION           *

                 *          MODULE             *

                 *                             *

                 * EOSAEL87  REV 00   27 OCT 87 *

                 *                             *

                 *******************************

                          XSCALE RUN #   1

     OPTIONS CHOSEN:   DESERT AEROSOL

                       WIND SPEED  10.00 M/S

                       HORIZONTAL PATH

                       WIDEBAND WAVELENGTH AVERAGE

               WIDEBAND AVERAGE: FROM   3.000 TO   5.000 UM

    EXTINCTION  ABSORPTION  SCATTERING     DISTANCE     TRANSMISSION

       1/KM        1/KM        1/KM           KM              %

    2.1446E-02  2.1142E-03  1.9331E-02      1.000        9.7878E+01

             TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .9788E+00

                            END EOSAEL RUN

STOP 000
```

5.8 Ice Fog

The transmittance for ice fog at a single wavelength of 4 µm is requested in the following file: The visibility is 0.8 km, a horizontal path of 1 km at the surface is specified, and the temperature is -35 °C. Several default values are accepted here because the ICEF record is not present. These values and the resulting action by the program are: ISOURC = 0 meaning no source values will be input, DECPER = 0.0 meaning the value of IWATER will decide the source mixture, IWATER = 0 meaning no open water nearby (thus DECPER (vehicles) = 0.56 and DECPER (heating flue) = 0.44), neither XMEAN nor XMODE specified meaning the program will calculate the mode radii r_c by equation (22).

```
WAVL       4.0

VIS        0.8

XSCALE

HORZ       1.0

AERO       10.0                           -35.0

DONE

END

STOP

C234567890123456789012345678901234567890123456789012345678901234567890123456789 0
C         1         2         3         4         5         6         7         8
```

This produces more involved output:

```
*******************************************************************************
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                      ********************************
                      *                              *
                      *    ELECTRO-OPTICAL SYSTEMS   *
                      *                              *
                      *  ATMOSPHERIC EFFECTS LIBRARY *
                      *                              *
                      *    NOT FOR OPERATIONAL USE   *
                      *                              *
                      * EOSAEL87 REV 2.1   02/23/90  *
                      *                              *
                      ********************************
WAVL      4.0
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .4000E+01 .4000E+01 .0000E+00
                                         BEGINNING          ENDING
             WAVENUMBER (CM**-1)          2500.000          2500.000
             WAVELENGTH (MICROMETERS)        4.000             4.000
             FREQUENCY (GHZ)             75000.000         75000.000
                                     VISIBILITY
                                       .80 KM
1
                      ********************************
                      *                              *
```

```
*        X S C A L E          *
*                             *
*      NATURAL AEROSOL        *
*         EXTINCTION          *
*           MODULE            *
*                             *
* EOSAEL87  REV 00   27 OCT 87 *
*                             *
*******************************

              XSCALE RUN #   1

OPTIONS CHOSEN:   SNOW MODEL

                  TEMPERATURE -35.00 DEGREES C

                  WIND SPEED    2.00 M/S  (DEFAULT VALUE)

                  DETECTOR RADIUS  10.00 CM  (DEFAULT VALUE)

                  HORIZONTAL PATH

                  WAVELENGTH    4.000 MICROMETERS

      SURFACE EXTINCTION  =  4.8613E+00 1/KM

              ABSORPTION  =  0.0000E+00 1/KM

              SCATTERING  =  0.0000E+00 1/KM

 SINGLE SCATTERING ALBEDO  =   .0000

EXTINCTION              DISTANCE              TRANSMISSION

  1/KM                     KM                      %

4.8613E+00               1.000                 7.7403E-01

      TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .7740E-02

                  END EOSAEL RUN

STOP 000
```

5.9 Slant Path Through a Cloud

The transmission over a slant path extending through a thin cloud is calculated here. The path is 10-km long with a 6° elevation beginning at the surface. The cloud is 700 m above the earth's surface and extends to 750 m. The extinction profile will be written to the file UG5. This file already exists in the directory in which XSCALE was run; this will be noted in the output.

```
WAVL      3.0       5.0

VIS       10.0

XSCALE

AERO      2.0                 87.0

SLNS      10.0      6.0

CLD       0.700     0.050     -1.0

PLOT       2.0

UG5

DONE

END

STOP

C234567890123456789012345678901234567890123456789012345678901234567890123456789 0

C         1         2         3         4         5         6         7         8
```

This produces the following output:

```
*****************************************************************************
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  EXECUTIVE ORDER 12470.  VIOLATION OF THESE EXPORT LAWS ARE SUBJECT TO
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                    *                              *
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                    *                              *
                    *    NOT FOR OPERATIONAL USE   *
                    *                              *
                    * EOSAEL87 REV 2.1   02/23/90  *
                    *                              *
                    ********************************
WAVL      3.0       5.0
 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
WAVL       .3000E+01 .5000E+01 .0000E+00
                                     BEGINNING           ENDING
             WAVENUMBER (CM**-1)      2000.000          3333.333
             WAVELENGTH (MICROMETERS)    3.000             5.000
             FREQUENCY (GHZ)         60000.000        100000.000
                                  VISIBILITY
                                   10.00 KM
1
                    ********************************
                    *                              *
```

```
*          X S C A L E          *
*                               *
*        NATURAL AEROSOL        *
*          EXTINCTION           *
*            MODULE             *
*                               *
* EOSAEL87  REV 00   27 OCT 87  *
*                               *
*********************************
```

```
xscale WARNING: FILE(                                         UG5          )
 WILL BE OVER WRITTEN
                         XSCALE RUN #   1
      OPTIONS CHOSEN:   URBAN AEROSOL MODEL
                        RELATIVE HUMIDITY  87.00 PERCENT
                        SLANT PATH
                        WIDEBAND WAVELENGTH AVERAGE
                      CLOUD CEILING HEIGHT IS  .700 KILOMETERS
                      CLOUD THICKNESS IS  .050 KILOMETERS
                      * * AVERAGE EXTINCTION CALCULATED FROM THE
                      GROUND UP TO THE CLOUD TOP * *
                      ASSUME CLEAR AIR PROFILE ABOVE
                   SLANT      VERTICAL     HORIZONTAL
                  DISTANCE    DISTANCE     DISTANCE      ANGLE
                    KM          KM            KM        DEGREES
                  10.000       1.045        9.945        6.00
                      PATH IS ABOVE THE SURFACE, ALTITUDE RANGES
                      FROM  .001 TO 1.046 KILOMETERS
              WIDEBAND AVERAGE: FROM   3.000 TO   5.000 UM
               EXTINCTION      DISTANCE      TRANSMISSION
                 1/KM             KM              %
```

```
1.1250E+00        10.000        1.3003E-03

TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .1300E-04

END EOSAEL RUN

STOP 000
```

This file UG5 has been written over with the extinction profile calculated in this run. The file looks like:

```
NUMBER OF POINTS   24          WAVELENGTH:   3.000

IAERO  ALT  RELHUM  VISEXT      IR EXT      IR PATHAVE

  2      1.    87.00 3.9121E-01 1.1295E-01 0.0000E+00
  2     70.    87.01 3.9198E-01 1.1319E-01 1.1145E-01
  2    135.    87.03 3.9347E-01 1.1364E-01 1.1240E-01
  2    198.    87.06 3.9627E-01 1.1450E-01 1.1293E-01
  2    258.    87.12 4.0140E-01 1.1606E-01 1.1348E-01
  2    315.    87.22 4.1061E-01 1.1888E-01 1.1420E-01
  2    369.    87.39 4.2683E-01 1.2384E-01 1.1525E-01
  2    421.    87.68 4.5511E-01 1.3252E-01 1.1684E-01
  2    470.    88.15 5.0438E-01 1.4771E-01 1.1926E-01
  2    515.    88.86 5.9116E-01 1.7466E-01 1.2300E-01
  2    558.    89.92 7.4778E-01 2.2386E-01 1.2883E-01
  2    597.    91.41 1.0414E+00 3.1924E-01 1.3820E-01
  2    633.    93.40 1.6184E+00 5.1216E-01 1.5368E-01
  2    664.    95.87 2.8017E+00 9.3359E-01 1.8031E-01
  2    690.    98.73 5.2797E+00 1.9640E+00 2.2906E-01
  2    700.   100.00 7.0000E+00 7.3430E+00 2.9088E-01
  4    747.   100.00 2.4128E+01 2.5310E+01 1.2951E+00
  4    750.   100.00 2.5601E+01 2.6856E+01 1.4020E+00
  4    756.   100.00 9.1653E+00 9.6144E+00 1.5300E+00
```

2	769.	50.00	1.5023E+00	2.5551E-01	1.5894E+00
2	803.	50.00	1.4453E-01	2.4582E-02	1.5277E+00
2	874.	50.00	4.5662E-02	7.7662E-03	1.4057E+00
2	980.	50.00	3.9255E-02	6.6765E-03	1.2541E+00
2	1046.	50.00	3.9035E-02	6.6391E-03	1.1757E+00

NUMBER OF POINTS 24 WAVELENGTH: 3.200

IAERO	ALT	RELHUM	VISEXT	IR EXT	IR PATHAVE
2	1.	87.00	3.9121E-01	8.6544E-02	0.0000E+00
2	70.	87.01	3.9198E-01	8.6720E-02	1.9683E-01

.

.

.

2	980.	50.00	3.9255E-02	4.7909E-03	1.2007E+01
2	1046.	50.00	3.9035E-02	4.7641E-03	1.1252E+01

NUMBER OF POINTS 24 WAVELENGTH: 5.000

IAERO	ALT	RELHUM	VISEXT	IR EXT	IR PATHAVE
2	1.	87.00	3.9121E-01	4.3620E-02	0.0000E+00
2	70.	87.01	3.9198E-01	4.3705E-02	6.4178E-01
2	135.	87.03	3.9347E-01	4.3869E-02	6.4724E-01
2	198.	87.06	3.9627E-01	4.4178E-02	6.5022E-01
2	258.	87.12	4.0140E-01	4.4743E-02	6.5325E-01
2	315.	87.22	4.1061E-01	4.5757E-02	6.5726E-01
2	369.	87.39	4.2683E-01	4.7542E-02	6.6307E-01
2	421.	87.68	4.5511E-01	5.0653E-02	6.7179E-01
2	470.	88.15	5.0438E-01	5.6067E-02	6.8505E-01
2	515.	88.86	5.9116E-01	6.5588E-02	7.0543E-01
2	558.	89.92	7.4778E-01	8.2729E-02	7.3709E-01

2	597.	91.41	1.0414E+00	1.1564E-01	7.8757E-01
2	633.	93.40	1.6184E+00	1.8066E-01	8.7028E-01
2	664.	95.87	2.8017E+00	3.2286E-01	1.0116E+00
2	690.	98.73	5.2797E+00	7.0997E-01	1.2775E+00
2	700.	100.00	7.0000E+00	7.7259E+00	1.9170E+00
4	747.	100.00	2.4128E+01	2.6630E+01	1.3383E+01
4	750.	100.00	2.5601E+01	2.8256E+01	1.4600E+01
4	756.	100.00	9.1653E+00	1.0116E+01	1.6061E+01
2	769.	50.00	1.5023E+00	1.7828E-01	1.6750E+01
2	803.	50.00	1.4453E-01	1.7151E-02	1.6091E+01
2	874.	50.00	4.5662E-02	5.4187E-03	1.4804E+01
2	980.	50.00	3.9255E-02	4.6584E-03	1.3207E+01
2	1046.	50.00	3.9035E-02	4.6323E-03	1.2375E+01

Some points concerning the slant path calculation may be made. The vertical step size is not constant; it depends on how quickly the visible extinction is changing. The more rapid the change, the smaller the step taken. There is always a step at a layer boundary (700 and 750 m). The altitude is given in meters. The profile is calculated from the surface up to the vertical extent of the path. The humidity begins at 87 percent, as specified, and grows to 100 percent at the cloud ceiling. For any altitude at which the visible extinction is greater than 7 km^{-1}, the humidity is set to 100 percent and the fog-one particle size distribution is used. Above the cloud, the humidity is a constant 50 percent and the surface aerosol particle size distribution is used. The IR extinction is calculated every 0.2 μm, but not all values are shown here. The IR PATHAVE column contains the IR extinction at the wavelength averaged over the path from the surface to the given altitude.

5.10 Multiple Run with Mistake

The following input file specifies a horizontal path of 2 km at the surface. A wideband average is again performed with a visibility of 0.8 km. First, transmittance through a radiation fog is requested. Then a drizzle is specified with a rain rate of 0.2 mm/h. Then the rain rate is increased to 6 mm/h. Because the `AERO` record has been entered, the variable `IAERO` has been reset; since it is not specified, the default is used (1, maritime).

```
WAVL      3.0        5.0

VIS       0.8

XSCALE

HORZ      2.0

AERO      5.0

GO

AERO      7.0         0.2

GO

AERO                  6.0

DONE

END

STOP

12345678901234567890123456789012345678901234567890123456789012345678901234567890

0        1         2         3         4         5         6         7         8
```

The output from this set of records is as follows:

```
*****************************************************************************

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WAVL       3.0        5.0

 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:

WAVL        .3000E+01 .5000E+01 .0000E+00

                                          BEGINNING          ENDING

              WAVENUMBER (CM**-1)          2000.000          3333.333

              WAVELENGTH (MICROMETERS)        3.000             5.000

              FREQUENCY (GHZ)             60000.000        100000.000

                                     VISIBILITY

                                       .80 KM

1

                    ********************************
                    *                              *
```

```
*          X S C A L E           *
*                                *
*       NATURAL AEROSOL          *
*         EXTINCTION             *
*           MODULE               *
*                                *
* EOSAEL87   REV 00    27 OCT 87 *
*                                *
**********************************
```

XSCALE RUN # 1

OPTIONS CHOSEN: FOG2 - LIGHT

RELATIVE HUMIDITY 100.00 PERCENT (DEFAULT VALUE)

HORIZONTAL PATH

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	ABSORPTION	SCATTERING	DISTANCE	TRANSMISSION
1/KM	1/KM	1/KM	KM	%
6.1693E+00	7.8943E-01	5.3799E+00	2.000	4.3791E-04

XSCALE RUN # 2

OPTIONS CHOSEN: RAIN - DRIZZLE

RAIN RATE .20 MM/HR

HORIZONTAL PATH

WIDEBAND WAVELENGTH AVERAGE

WIDEBAND AVERAGE: FROM 3.000 TO 5.000 UM

EXTINCTION	DISTANCE	TRANSMISSION
1/KM	KM	%
1.8462E-01	2.000	6.9126E+01

XSCALE RUN # 3

OPTIONS CHOSEN: AEROSOL MODEL WAS NOT RECOGNIZED

MARITIME AEROSOL MODEL [BY DEFAULT]

```
                    RELATIVE HUMIDITY  70.00 PERCENT  (DEFAULT VALUE)

                    HORIZONTAL PATH

                    WIDEBAND WAVELENGTH AVERAGE

               WIDEBAND AVERAGE: FROM   3.000 TO   5.000 UM

 EXTINCTION  ABSORPTION  SCATTERING     DISTANCE     TRANSMISSION

   1/KM        1/KM        1/KM           KM              %

1.8207E+00  2.4266E-01  1.5781E+00      2.000        2.6214E+00

          TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .2621E-01

                        END EOSAEL RUN

STOP 000
```

5.11 Slant Path and Boundary Defaults Dependence on Visibility

The following two input files show how a small change in the input records can cause XSCALE to report two different predictions. The only difference in the inputs is in the `VIS` record; first the `VIS` is set to 0.21 km, then 0.1 km. As the output shows, the first run is the expected calculation: a 5-km slant path through a radiation fog. The second run calculated the transmission through a heavy advection fog. The fog thickness in the first run is 60 m; since a radiation fog is the aerosol, the value of `AINVHT` is used. The fog thickness is 90 m in the second run; since an advection fog is the aerosol employed, the value of `THICK` is used. The `VIS` value is the cause of the two predictions; if the `VIS` is poor (less than 0.2 km), XSCALE will use the advection fog particle size distribution for scaling the visible extinction to the IR extinction.

```
WAVL     8.0      12.0

VIS      0.21

XSCALE

AERO     5.0

SLNS     5.0      10.0
```

```
CLD       0.0       0.09      0.06

DONE

END

STOP

12345678901234567890123456789012345678901234567890123456789012345678901234567890

0         1         2         3         4         5         6         7         8
```

The poor visibility file is as follows:

```
WAVL      8.0       12.0

VIS       0.1

XSCALE

AERO      5.0

SLNS      5.0       10.0

CLD       0.0       0.09      0.06

DONE

END

STOP

12345678901234567890123456789012345678901234567890123456789012345678901234567890

0         1         2         3         4         5         6         7         8
```

The output of the first file is as follows:

```
********************************************************************************
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                      *                              *
                      ********************************
 WAVL      8.0        12.0
  NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:
 WAVL        .8000E+01 .1200E+02 .0000E+00
                                         BEGINNING           ENDING
               WAVENUMBER (CM**-1)        833.333           1250.000
               WAVELENGTH (MICROMETERS)     8.000             12.000
               FREQUENCY (GHZ)          25000.000          37500.000
                                     VISIBILITY
                                       .21 KM
 1
                      ********************************
                      *                              *
```

```
*         X S C A L E          *
*                              *
*      NATURAL AEROSOL         *
*        EXTINCTION            *
*          MODULE              *
*                              *
* EOSAEL87  REV 00   27 OCT 87 *
*                              *
********************************
           XSCALE RUN #   1

OPTIONS CHOSEN:  FOG2 - LIGHT

        RELATIVE HUMIDITY 100.00 PERCENT  (DEFAULT VALUE)

        SLANT PATH

        WIDEBAND WAVELENGTH AVERAGE

      THICKNESS OF RADIATION FOG IS  .060 KILOMETERS

      ASSUME CLEAR AIR PROFILE ABOVE.

   SLANT       VERTICAL    HORIZONTAL
  DISTANCE     DISTANCE    DISTANCE     ANGLE
     KM           KM          KM        DEGREES
   5.000         .868        4.924      10.00

       PATH IS ABOVE THE SURFACE, ALTITUDE RANGES
       FROM  .001 TO  .869 KILOMETERS

WIDEBAND AVERAGE: FROM   8.000 TO  12.000 UM

 EXTINCTION      DISTANCE      TRANSMISSION
    1/KM            KM              %
 6.6685E-01        5.000        3.5642E+00

TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .3564E-01

                END EOSAEL RUN

STOP 000
```

The second input file produces the following output:

```
*******************************************************************************

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                  *                              *

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WAVL      8.0        12.0

 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:

WAVL       .8000E+01 .1200E+02 .0000E+00

                                    BEGINNING          ENDING

            WAVENUMBER (CM**-1)       833.333         1250.000

            WAVELENGTH (MICROMETERS)    8.000           12.000

            FREQUENCY (GHZ)         25000.000        37500.000

                                 VISIBILITY

                                   .10 KM

1

                  ********************************

                  *                              *
```

```
*         X S C A L E          *

*                              *

*      NATURAL AEROSOL         *

*         EXTINCTION           *

*           MODULE             *

*                              *

* EOSAEL87  REV 00   27 OCT 87 *

*                              *

********************************

              XSCALE RUN #   1

OPTIONS CHOSEN:   FOG1 - HEAVY

                  RELATIVE HUMIDITY 100.00 PERCENT  (DEFAULT VALUE)

                  SLANT PATH

                  WIDEBAND WAVELENGTH AVERAGE

                THICKNESS OF ADVECTION FOG IS  .090 KILOMETERS

                ASSUME CLEAR AIR PROFILE ABOVE.

             SLANT      VERTICAL    HORIZONTAL

            DISTANCE    DISTANCE    DISTANCE     ANGLE

               KM          KM          KM       DEGREES

             5.000        .868        4.924      10.00

                 PATH IS ABOVE THE SURFACE, ALTITUDE RANGES

                 FROM  .001 TO  .869 KILOMETERS

          WIDEBAND AVERAGE: FROM   8.000 TO  12.000 UM

           EXTINCTION      DISTANCE      TRANSMISSION

              1/KM            KM              %

           7.2382E+00        5.000        1.9163E-14

         TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .1916E-15

                         END EOSAEL RUN

STOP 000
```

5.12 Response Function Option

The use of the RESF record is demonstrated next. An 8 – 12 μm band average is requested. Only two response function values are input, both specified at wavelengths outside the requested band. This specifies a very simple trapezoidal shaped response function. As such, this is not very real, but is presented as a simple example.

```
WAVL     8.0       12.0
VIS      2.4
XSCALE
AERO     5.0
SLNS     5.0       10.0
CLD      0.0       0.09      0.06
RESF     2.0
    .7000E+01 .1000E+00
    .1210E+02 .8000E+00
DONE
END
STOP
12345678901234567890123456789012345678901234567890123456789012345678901234567890
0        1         2         3         4         5         6         7         8
```

```
********************************************************************************

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                      *                              *

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                      *                              *

                      ********************************

WAVL      8.0       12.0

 NOTE: THAT THE ABOVE CARD WAS MODIFIED FOR CONSISTENCY TO:

WAVL       .8000E+01 .1200E+02 .0000E+00

                                        BEGINNING          ENDING

             WAVENUMBER (CM**-1)         833.333          1250.000

             WAVELENGTH (MICROMETERS)      8.000            12.000

             FREQUENCY (GHZ)           25000.000         37500.000

                                   VISIBILITY

                                    2.40 KM

1

                      ********************************

                      *                              *
```

```
*        X S C A L E          *
*                             *
*      NATURAL AEROSOL        *
*         EXTINCTION          *
*           MODULE            *
*                             *
* EOSAEL87  REV 00   27 OCT 87 *
*                             *
*******************************
```

```
A non response function format input record encountered
    .7000E+01 .1000E+00
A NON EOSAEL FORMAT INPUT CARD ENCOUNTERED
    .1210E+02 .8000E+00
                TOTAL TRANSMITTANCE FOR ALL SOURCES IS:  .0000E+00
                              END EOSAEL RUN
STOP 000
```

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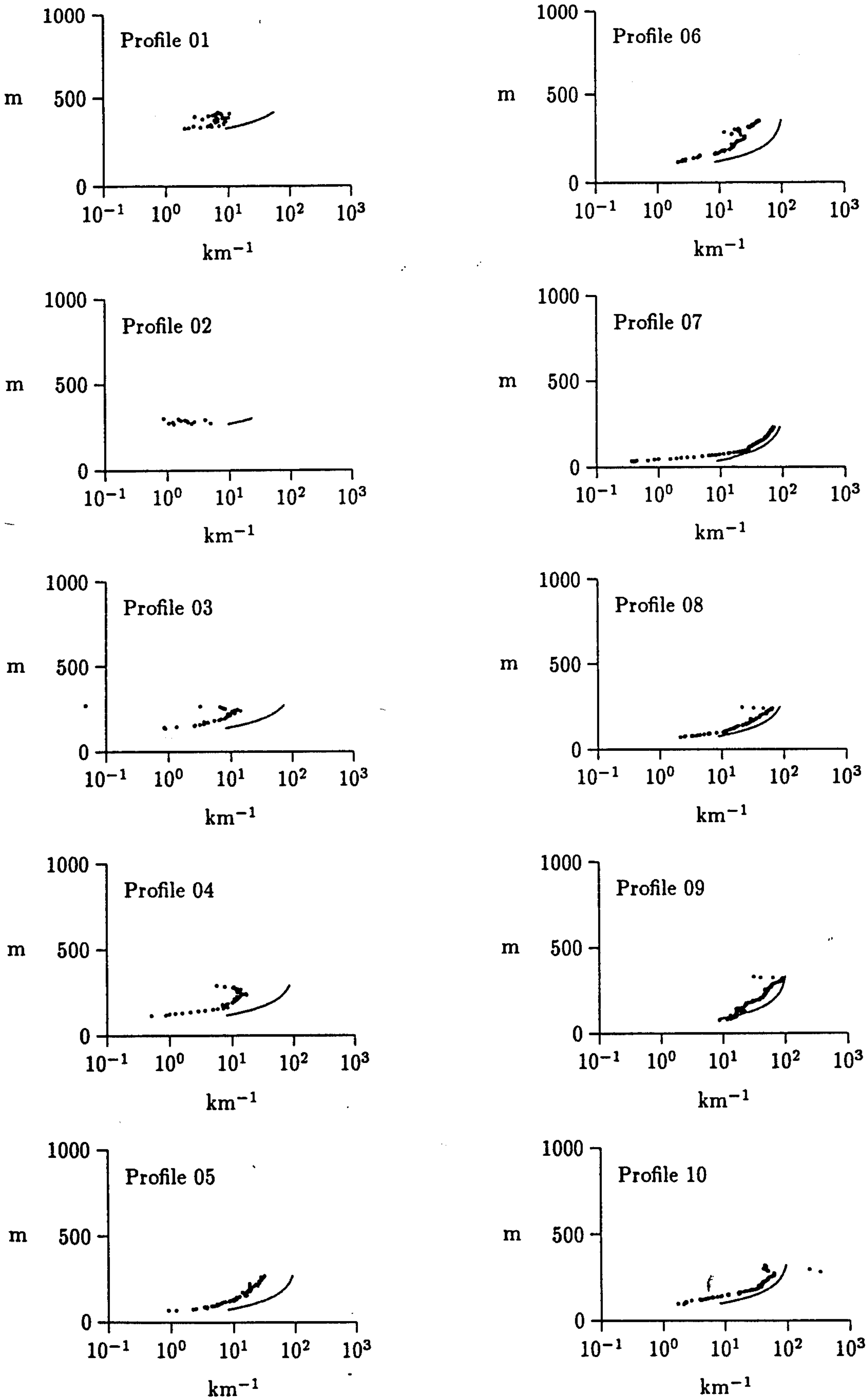
Acronyms and Abbreviations

AAODL	Atmospheric Aerosol Optics Data Library
ARL	Army Research Laboratory
ASL	Atmospheric Sciences Laboratory
BED	Battlefield Environment Directorate
EO	electro-optical
IR	infrared
LOS	line-of-sight
SNOW	Scenario Normalization for Operations in Winter

Appendix

Plots Showing the Meppen 80 Measured Extinction at 10.6 μm and the XSCALE Calculated Extinction

For clarity, only the in-cloud part of the vertical profiles are shown. The measurements are represented by '.', the calculation by a solid curve. The vertical axis is altitude in meters; the horizontal axis is extinction in km^{-1} on a log scale. The profiles are identified by flight numbers and are in chronological order.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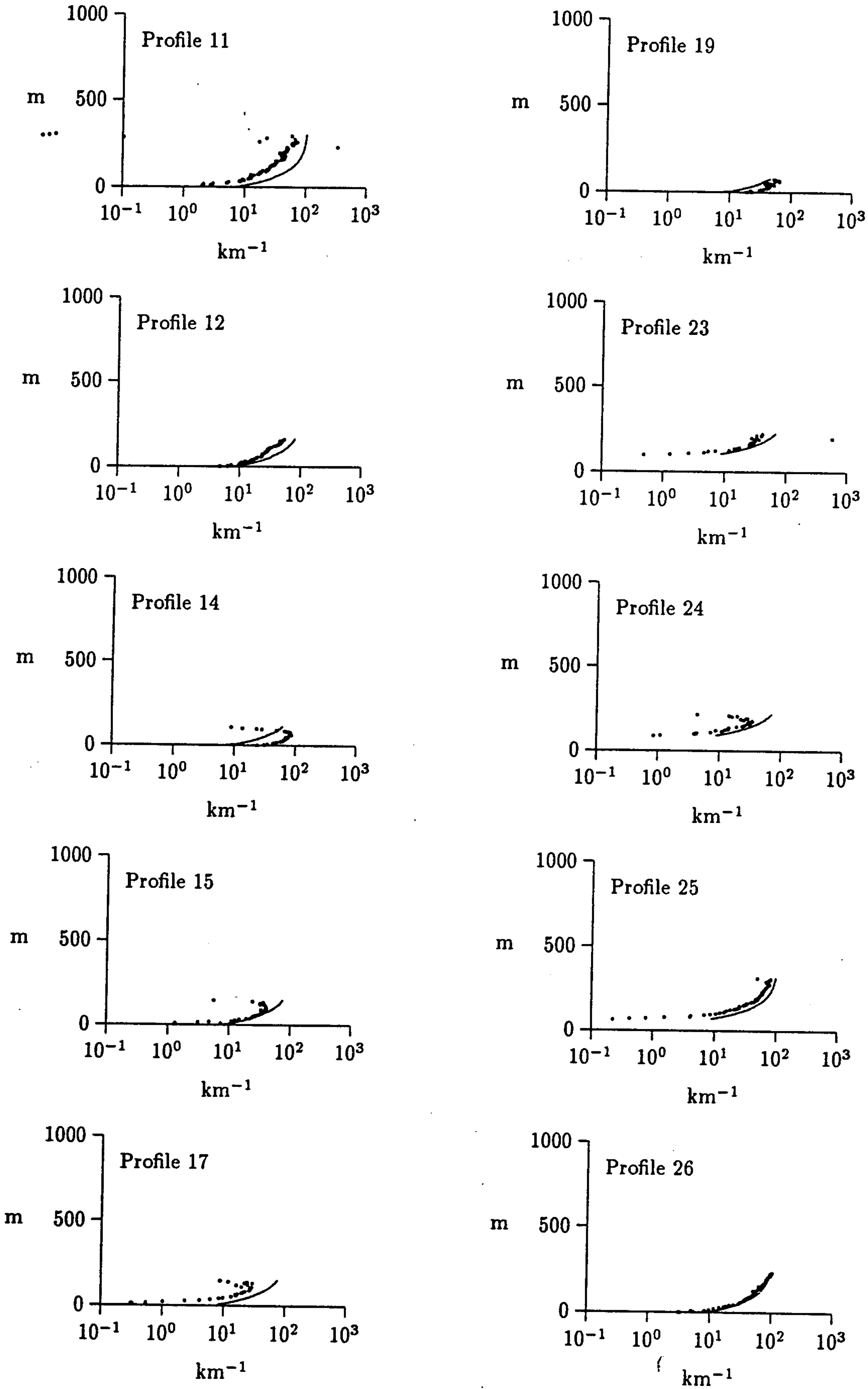

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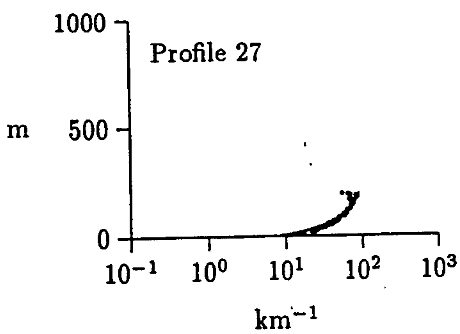
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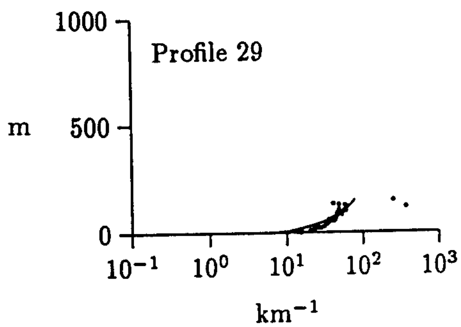
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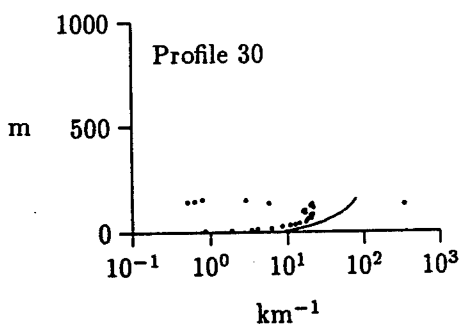
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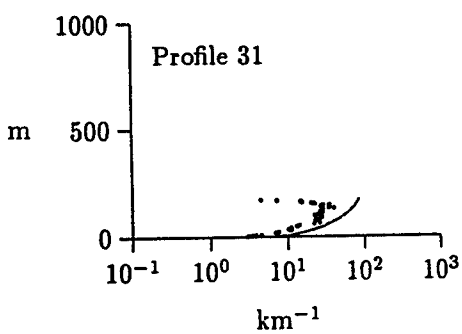
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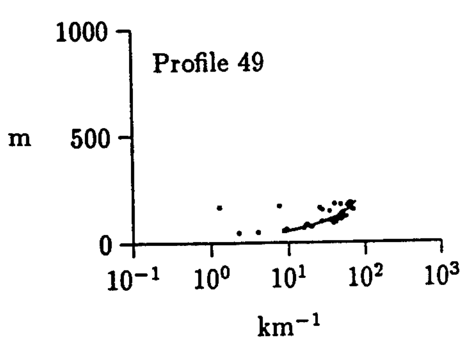
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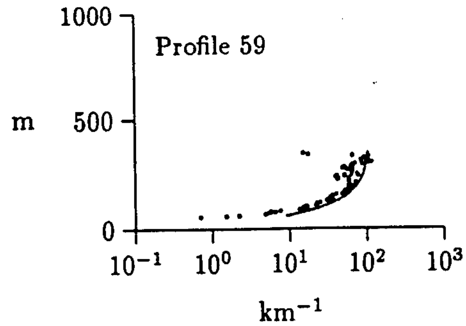
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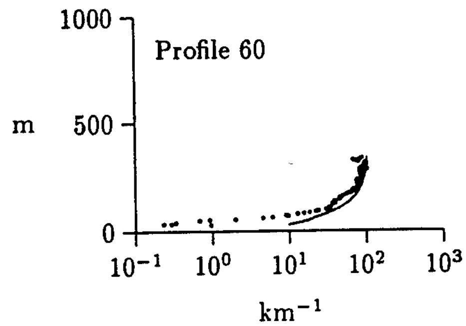
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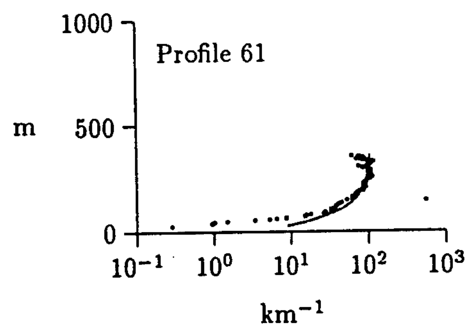
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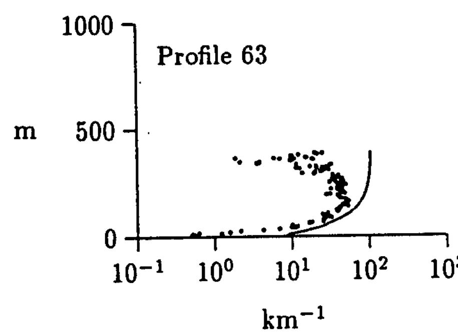
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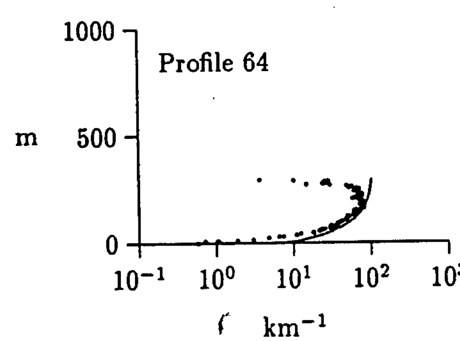
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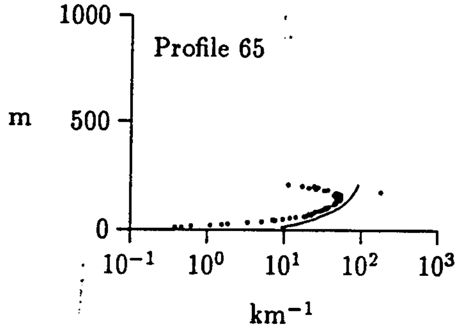
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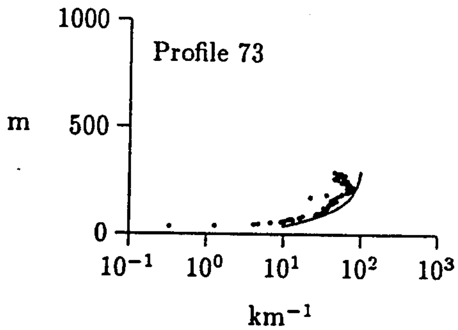
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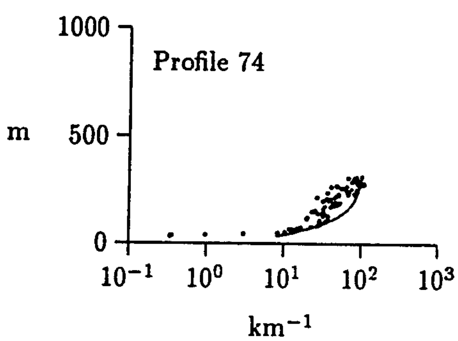
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